OCULAR ASYMMETRIES AND BINOCULAR VISION

Susan Heather Wright

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by

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This thesis is the unaided work of Susan Wright and has not been accepted in any previous application for a higher degree. It is submitted for the Degree of the Doctor of Philosophy at the University of St. Andrews, admission date 1st October 1977, under Ordinance General No. 12.

The conditions of the Resolution and Regulations have been fulfilled.

Susan Wright

Brian Rogers (Dr.)

The University of St. Andrews.

Ocular Asymmetries in Binocular Vision.

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Summary.

This study was undertaken to investigate ocular asymmetries in binocular vision using several dichoptic and binocular viewing paradigms.

The literature on eye dominance was reviewed and it revealed that little emphasis both theoretically and experimentally had been placed on binocular viewing situations. The nature of the eye dominance tests and the dichotomous classification of the results suggested that one eye's image was competing against the other. The relationship between the different eye dominance tests was not clear.

A new approach to the study of ocular dominance has been developed in this thesis with specific attention to binocular vision and viewing situations. The term eye dominance has been replaced by the term ocular asymmetries to describe the results and measures derived from these procedures and the nature of the binocular visual approach.

The experimental work is divided into three sections. Section one, is concerned with a binocular rivalry procedure using real images and afterimages. Section two, involves a stereoscopic viewing procedure and depth discrimination task with selective attenuation of the stereo-displays. Section three, investigates the interocular transfer of the spatial frequency shift. Measures of ocular asymmetry were derived from all three procedures and the three sets of scores were positively related. This measure gives both the direction and the degree of the ocular asymmetry.

The results indicate that ocular asymmetries are a valid feature of binocular vision. The new measure derived from the depth discrimination experiment provides a quantitative and consistent measure of ocular asymmetry. Special attention has been directed at the involvement of eye movements in all three paradigms and as the underlying factor in the asymmetry results. On the basis of the findings it was suggested that the asymmetry may reside in the binocular system controlling eye movements or reflect an asymmetry in processing speeds of the images from the two eyes arriving at the binocular site. The ocular asymmetry measures do not necessarily indicate eye movements are asymmetrical.

It is recommended that ocular asymmetry is a variable to be studied in other investigations of binocular vision and binocular interactions.

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PART I

INTRODUCTION

CHAPTER 1

Introduction

When both eyes are stimulated by disparate images one single percept is usually experienced in one visual direction. The disparity of the images is the basis to visual stereoscopic depth perception. However, the object is seen in slightly different directions by each eye and the visual system functions as if there is one hypothetical centrally placed eye or "cyclopean eye" positioned midway between the eyes (Hering, 1879/1964).

Binocular vision is possibly unique among the senses for the level of integration of the inputs from the eyes. Single vision is achieved and maintained by vergence and other eye movements. For spatial co-ordination visual information is combined with information from the motor system and other senses. To locate an object in space the images on the retinae are integrated with information about the position of the eyes in the head, the head with the body and calibrated with the motor system.

Historically, binocular single vision has been related to motor laterality and eye dominance. In normal binocular vision one eye was believed to become dominant and the visual direction of objects were specified by that eye. Intergration of the two images was not believed to be an important feature in single vision.

There is no single definition of the term eye dominance, it depends on the test used to measure it. However, if one eye performs better in a visual task either with monocular or binocular/dichoptic testing then that eye is designated the dominant eye.

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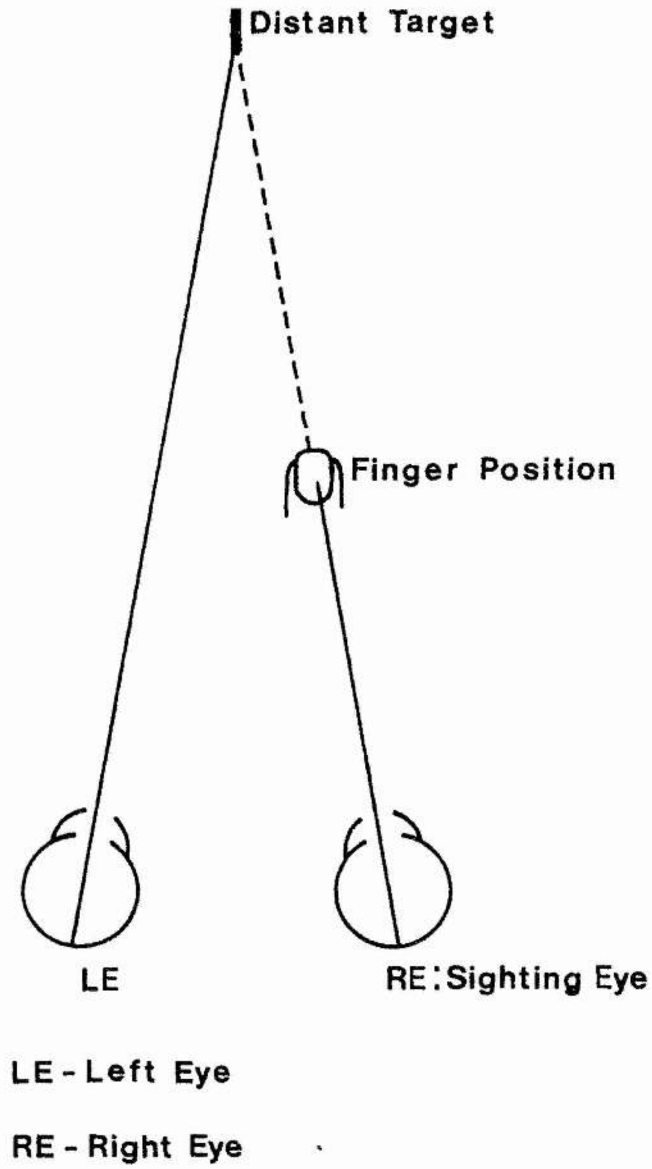
The work reported in this thesis is an investigation into asymmetries in binocular vision using various binocular and dichoptic viewing paradigms. The work involved an investigation of the eye dominance literature and the eye dominance tests, and the implications of this work for binocular vision was reviewed. Part I is an historical review of the eye dominance literature, the theories of eye dominance and the related studies on ocular asymmetries in binocular vision. The following sections include the experimental studies on ocular asymmetries in binocular vision.

1.1. Historical Background

Eye dominance was first mentioned by Porta in 1593 in his De Refractionie (Schoen and Scofield, 1935) where he described the phenomenon of visual alignment. The finger is aligned with a distant object while both eyes remain open (see Fig 1.1). The alignment of the two objects is carried out with one eye which can be identified by closing one or other eye and noting with which eye the finger and the object remain aligned. This eye was termed the dominant eye. Eye dominance appears not to be mentioned in the literature until the reports of Donders (1864) and Humphrey (1861). The latter was concerned with the relationship of "eyedness" ie. eye dominance with hand dominance believing ocular dominance was the cause of the laterality effects.

By the 1920's there was a proliferation of tests measuring eye dominance the majority of which were modifications of the simple alignment procedure outlined above. The tests became known as the sighting dominance tests. The interest in this visual asymmetry was related to the increased interest in handedness and motor laterality and many studies were concerned with finding a relationship between the two. Stevens (1909) pointed out that it was impossible in binocular vision to distinguish between one visual field and the other and anatomically the

Fig 1.1. The Position of the Finger when in Alignement with a Distant Target using the Sighting Dominant Eye.



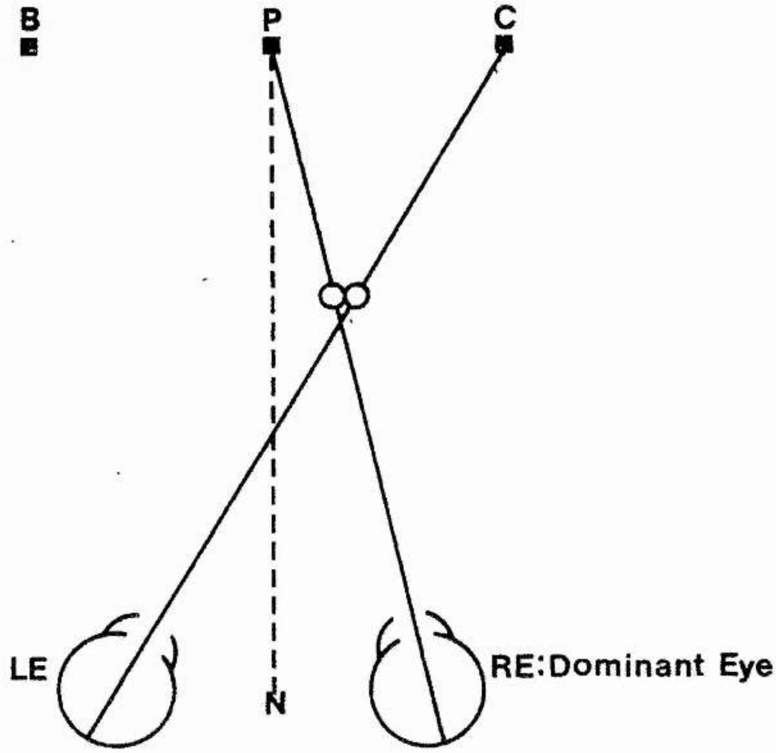
visual fields of each eye are represented in both hemispheres. However, researchers continued to a) establish a relationship between laterality and eye dominance using more elaborate sighting tests and b) use the dichotomous classification of left eye dominance or right eye dominance which followed the same procedure used in tests of laterality.

Low correlations were reported between ocular dominance tests and laterality tests. Geldard and Crockett (1930) and Smith (1933) reported near zero correlations. Parson (1924) published a book called "Lefthandedness" in which he described the manuscope, a device for measuring eye dominance that gave a dichotomous classification. The manuscope was believed to determine "handedness" by measuring "eyedness" ie. the sighting eye. The device consisted of a dark box, with a wide aperture that fitted over the eyes and tapered to a small aperture 1 X 1/8" wide. Shutters to the left and right of the midline occluded the left and right lines of sight. Three diagrams were placed 2' in front of the subject (see Fig 1.2) marked B, P, C. B and C were covered. Diagram P was viewed as the subject looked through the manuscope. B and C were exposed and the subject was required to state which diagram , B or C he could see. If C was reported, the subject was right eyed, and left eyed if B was reported.

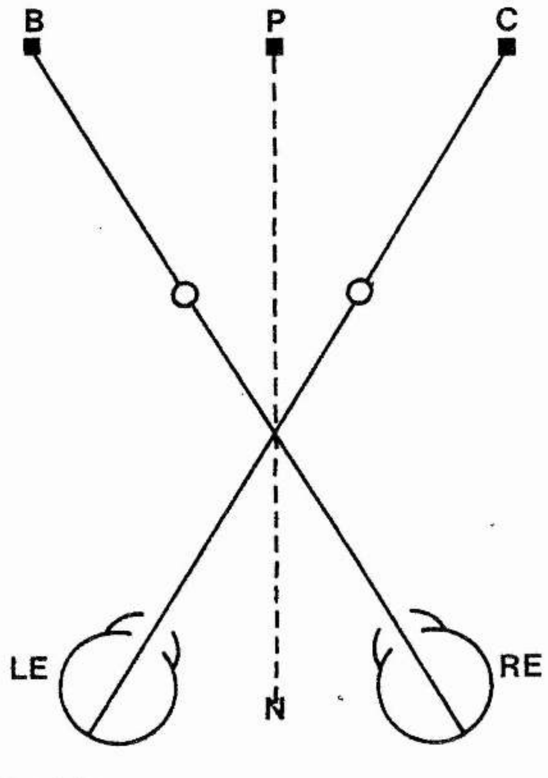
Parson provided results from 877 school children using the manuscope and reported that 69.3% were right eyed, 29.3% left eyed and 1.37% impartial (ie. truly binocular). Cuff (1928) reported similar percentages. Cuff (1930) redesigned the manuscope and called it the manoptometer. Lund (1932) adopted this device and called it the monoptometer. The monoptometer consisted of a circle mounted on a moveable rod with a distant fixation ring. The subject was required to bring the circle into line with the fixation ring. The lateral position of the rod either side of the median line indicated which eye was dominant . Both authors believed these devices measured direction and degree of dominance; consistent settings of the rod from the midline on successive trials was taken to indicate a strong eye dominance, inconsistent settings reflected a weak dominant eye. Cuff (1930, 1931) found correlations of 0.08 and 0.04 for 237 school children and 109 students respectively in the manoptometer test and nine other sighting tests, with results from a handedness questionnaire.

Fig 1.2. The Manuscope (taken from Parson, 1924, p79 and 84): Lines of sight for a) a Right Eye Dominant Subject and b) a Subject with No Sighting Dominance.

a) Right Dominant Subject views P and reports seeing C.



b) A Subject who is assumed to have "pure" binocular vision ie. no sighting eye sees both B and C.



PN = Median Line

O = Images of Small Aperture of Manuscope.

It was also thought that the eye with the better acuity would also be the eye classified as dominant in the sighting tests. Gahagan (1933) concluded after testing 100 subjects that acuity dominance, ie. the eye with the higher acuity score was not related to ocular dominance and that they were independent visual phenomena. Eye dominance was measured by the hole in the card sighting test.

Not only was dominance as measured by the sighting tests found to be unrelated to handedness and acuity but also there was some disagreement between the results from the different sighting dominance tests themselves. Buxton and Crosland (1937) reported high reliability for each test of dominance, ie. the manoptoscope, hole in the card, a ring sighting test and an aiming test. The different dominance tests are described in Appendix A, page 261. However, the inter correlations between these tests ranged from 0.45 to 0.71 for 86 subjects tested. This suggests that these sighting dominance tests may be measuring different factors or different aspects of sighting behaviour. Gronwall and Sampson (1971) reported a higher mean correlation for five sighting dominance tests of $r = 0.65$ for 50 subjects. These tests included the hole in the card, ring, box, pointing and the Miles A-B-C sighting tests. The authors concluded that eye dominance or preference was the result of the consistent use of one eye in alignment tests or procedures.

The studies on eye dominance have been preoccupied with finding a relationship between sighting and other visual and motor tasks for example, visual acuity and motor laterality. This pre-occupation has obscured the nature and function of ocular dominance in binocular vision and hence what aspect of visual functioning those tests of dominance are measuring. There has been little mention in the eye dominance literature about the possible mechanisms involved for the preferential use of one eye over the other. More importantly the studies have not addressed the relation of eye dominance to binocular visual performance:-is eye dominance the superiority of one eye over the other in normal binocular viewing situations and is it truly dichotomous?

1.2. Judgements of Visual Direction

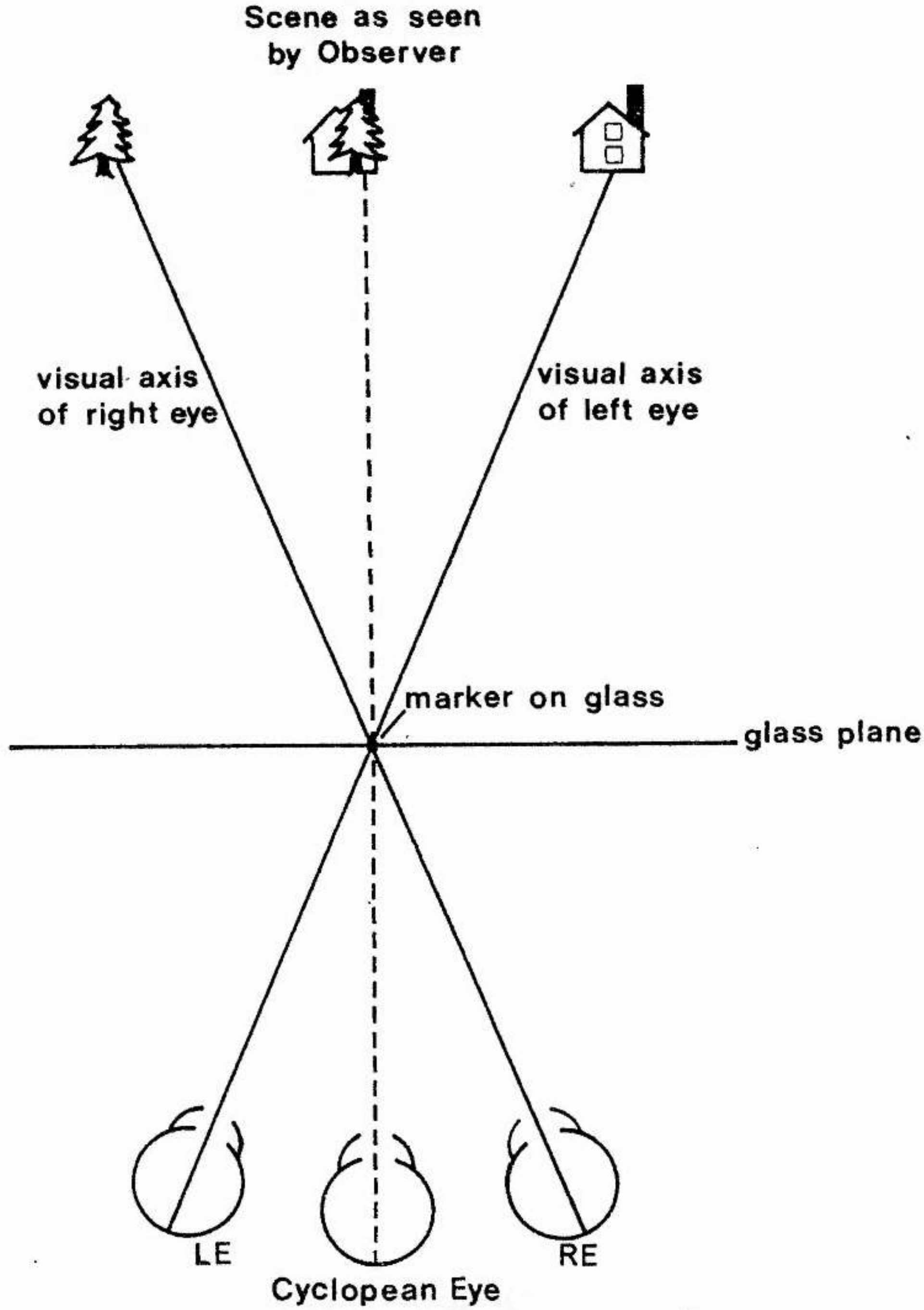
Judgements of visual direction for objects in space would be much easier if we had only one eye. There would be a one to one correspondence of the direction of the object with the position or location of the image on the retina. This information together with the angular position of the eye in the head would provide the egocentric visual information required for judging directions of objects in space (egocentric means the direction of objects in space in relation to the position of the head and eyes).

However, with binocular vision, the situation is more complicated. Some authors have postulated that the sighting dominant eye acts as a directionalising eye in the manner described above (Parson, 1924; Sheard, 1926; Walls, 1951; Rubin and Walls, 1969). The sighting eye is the centre from which object directions are judged. A centre point or origin is required in space perception for the geometry of the polar coordinates that determine the position of an object in space. However, an alternative hypothesis holds that this centre point is located somewhere on the interocular axis often assumed to be midway between the eyes (Wells, 1792; Hering, 1868/1977, 1879/1942). Hering (1868/1977) argued for the existence of a cyclopean eye and the principles of visual direction and formulations by Ono (1979) are discussed below. Wells (1792) had reported similar findings and propositions for visual direction as Hering but many years earlier.

1.2.1. The Cyclopean Eye

Hering states, "For any given two corresponding lines of direction, or visual lines, there is in visual space a single visual direction line upon which appears everything which actually lies on the pair of visual lines." (Hering, 1879/1942, page 41). Thus objects that stimulate each foveae are seen as if on a single line passing through the point assumed to be midway between the eyes. Wells (1792) calls this line the common axis. This was demonstrated by Hering using the diagram shown in Fig 1.3. The observer locates an object for example, the tree with the left eye and marks its position on the plane of glass. With the right eye only the marker is fixated and then beyond this another object is located eg. the chimney of the house. With both eyes open and fixation

Fig 1.3. Diagram to Demonstrate Herings' Principles of Visual Direction (Hering, 1879/1942): The Window Pane Demonstration.



Principle 1: "Objects producing superimposed retinal images for a given position of the eye are judged to be aligned.", (ie. retinal loci determine visual directions).

Principle 2: "All visual lines of both eyes are judged to point to one of the same projection centre.", (ie. a common centre for visual direction, the cyclopean eye).

Postulate : Objects on the visual axis of either eye are judged to be on the same line passing through the projection centre and intersection of the visual axes.(taken from Howard and Templeton, 1966) directed to the mark on the glass, the tree and chimney are seen in the same position, and one may rival with the other in clarity or form. Only one disparate image of each object is shown in Fig 1.3. The chimney and tree are judged to be in the same visual direction on a line passing through the cyclopean eye and the intersection of the two lines of sight. This implies that the orientations of both eyes are monitored. The chimney and the tree stimulate corresponding regions of the two retinae and therefore result in identical visual directions.

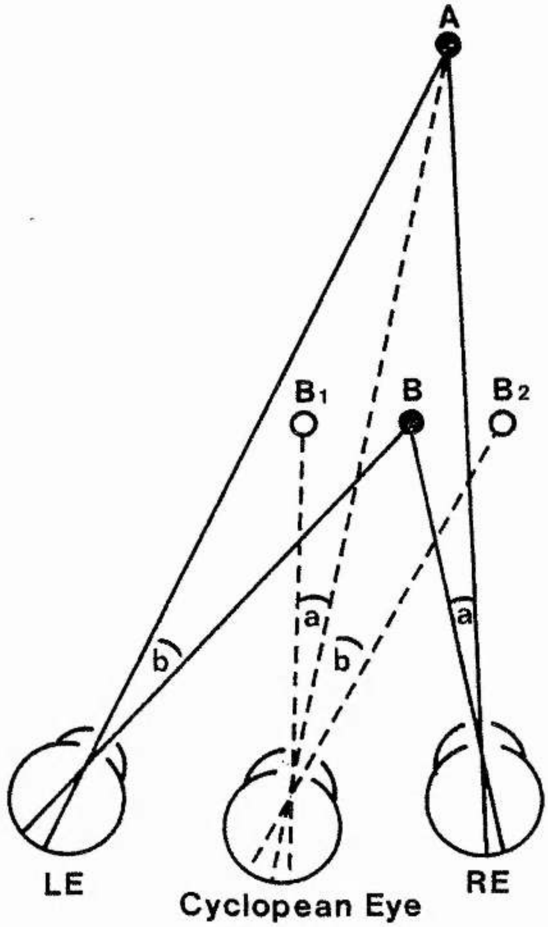
The projection centre or cyclopean eye has also been referred to as the egocentre or binoculus. These principles of visual direction have been stated by other authors (Fry, 1950; Ogle, 1962; Howard and Templeton, 1966; Howard, 1982) and have been reformulated by Ono (1979).

It was stated above that the chimney and tree may rival and that they form the cyclopean field. If slightly disparate fused images are viewed, the visual direction of the object is frequently the average of the visual directions specified by each monocular image. For rivalrous images it will correspond to the dominant image. For widely disparate images diplopia will be experienced.

Visual directions for objects that do not stimulate the centre of the foveae of the eyes will be misjudged. The visual direction of an object will be specified by the angular position of the eyes or visual lines of sight and the loci of the images of the two eyes (see Fig 1.4). Object B is not fixated and is seen double, the images B1 and B2 appear at particular angular deviations from the line joining the fixation point and cyclopean eye. Experimental evidence for the apparent location of the images has been provided by Ono and Angus (1974) in an adaptation study on motor-sensory coordination and conflict.

It would be expected that these non-veridical locations of objects would interfere with normal life, although these illusory locations are rarely experienced in normal viewing. The object that is fixated is the object that is usually attended and saccadic eye movements are not programmed to illusory locations but to the actual veridical location of the object (Ono and Nakamizo, 1977). It is possible that one of the roles of eye movements is to correctly locate objects and their visual directions by changing fixation from one object to another (Ono, 1979).

Fig 1.4. Diagram to Demonstrate the Illusory Locations of Objects in Front of the Fixation Point Predicted from the Principles of Visual Direction.



Fixation on Point A, Target B appears double. The apparent location of the diplopic images (0) are seen at B1 and B2. The visual angle subtended by A and B at the eyes are transferred to the cyclopean eye. B1 and B2 appear as if on two visual lines outside that joining A and B.

Both eyes are monitored during binocular viewing to determine the position of visual objects. Most judgements of visual direction are made as if from a point in the median plane of the head. In a sighting task it would be expected that the position of both eyes would be monitored. The principles and the postulate of visual direction will predict the apparent change in direction of stimuli with a change in accommodative vergence from one object to another. Fig 1.5 demonstrates how both eyes are monitored together with the position of the egocentre for determination of the visual directions of the fixated and non-fixated objects.

Eye dominance and especially sighting dominance are concerned with the judgements of object directions in space and also single vision. The theories of ocular dominance are discussed below and re-appraised in relation to the principles of visual direction as outlined above.

1.3. Theories of Ocular Dominance

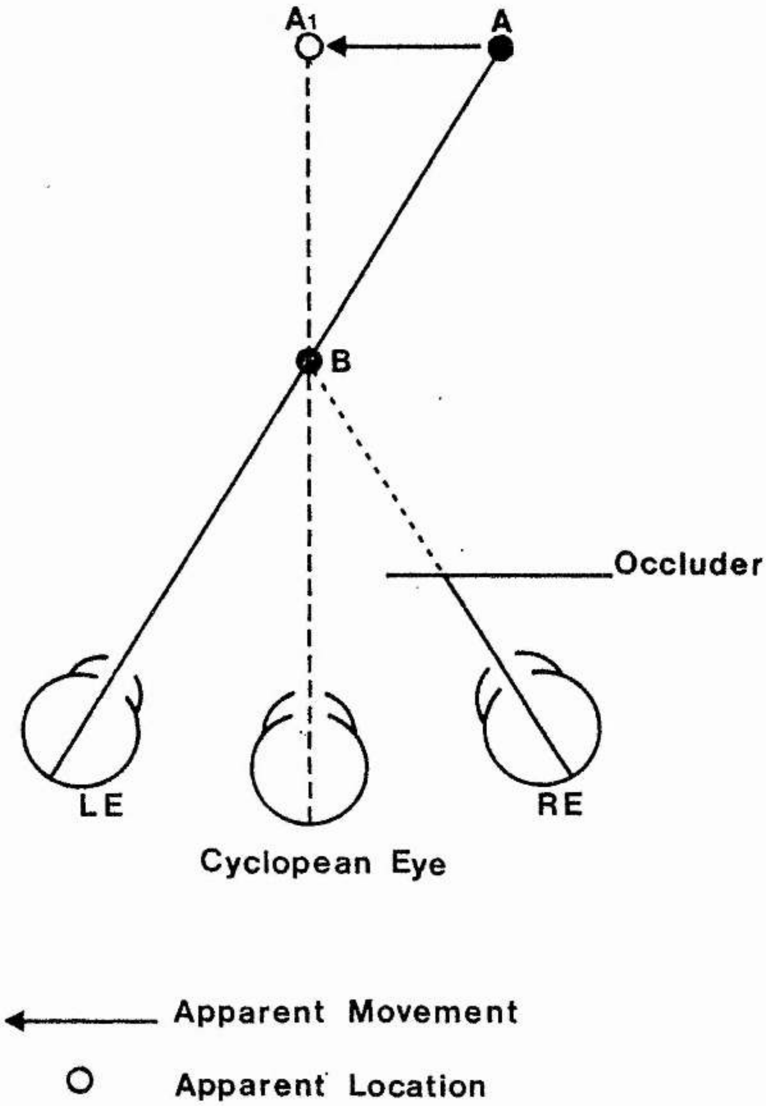
The early work on eye dominance was carried out without any theoretical views as to its relation with visual perception and function in binocular vision. It was seen as a further extension of motor laterality which influenced the type of tests carried out and the type of classification procedure adopted. Why one eye in these tests performed differently from the other was not addressed. There have been two attempts at formulating a theory of ocular dominance which will be discussed below together with one author's classification of the tests. Both theories are very poor at explaining the dominance effects as no mechanism or process is suggested as to the basis of eye dominance. The types of measures known to test eye dominance are classified by these authors without furthering the understanding as to what eye dominance is in relation to binocular vision.

1.3.1. Walls's Theory of Ocular Dominance

Sighting dominance measures appear to demonstrate that visual directions of objects in space are processed by the sighting eye only. The consistent use of this eye led Parson to believe that it was from this eye that visual directions are judged, ie. it was the centre for judgements of visual direction (Parson, 1924). This was elaborated upon

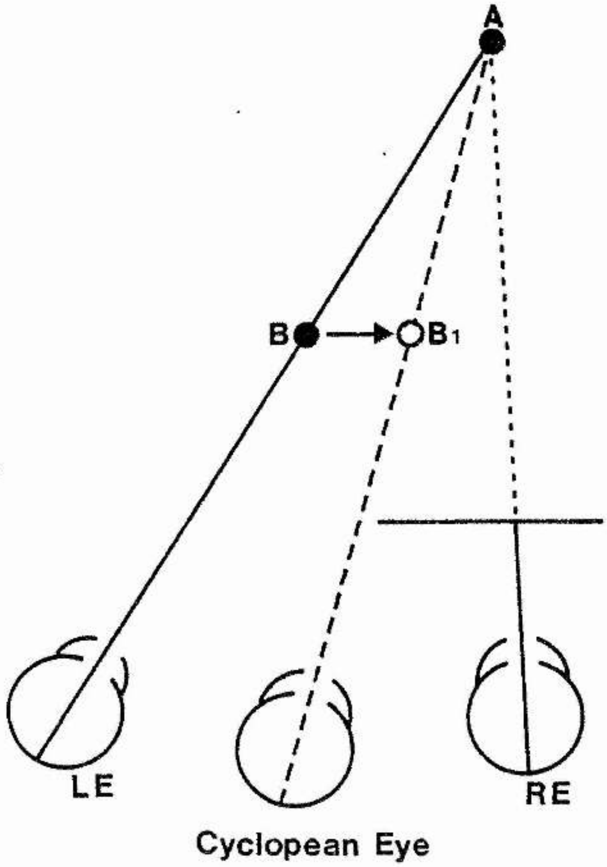
Fig 1.5. Apparent Movement of a Distant and Near Target with a Change in Accommodative Vergence Predicted from the Principles of Visual Direction while one eye is occluded (Ono, 1979).

a) A and B aligned with the Left Eye (LE).



(continued)

b) With a change in accommodative vergence from B to A, there is apparent movement of B to B1. This movement would also occur with the left eye occluded and A and B aligned with the right eye.



by Walls (1951) to formulate the theory on ocular dominance (also stated by Rubin and Walls, 1969).

After surveying the literature on eye dominance (the majority of which was concerned with alignment or sighting tasks) Walls proposed that there were 25 criteria for establishing eye dominance and divided them into five groups as follows; Group 1 were those tests concerned with sensory components such as the rivalry tests. Group 2 encompassed all the sighting tests that were assumed to involve motor components such as eye stability . Group 3 included the criteria resulting from the consequence of having a motor dominant eye eg. this eye diverges less when covered during fixation of a distant object. Group 4 includes the behavioural consequences of having a dominant eye eg. the holding of a card up to that eye to read. Group 5 includes an ad-hoc collection of criteria that did not fit into the above groups such as acuity dominance, and the relation of "eyedness" and "handedness".

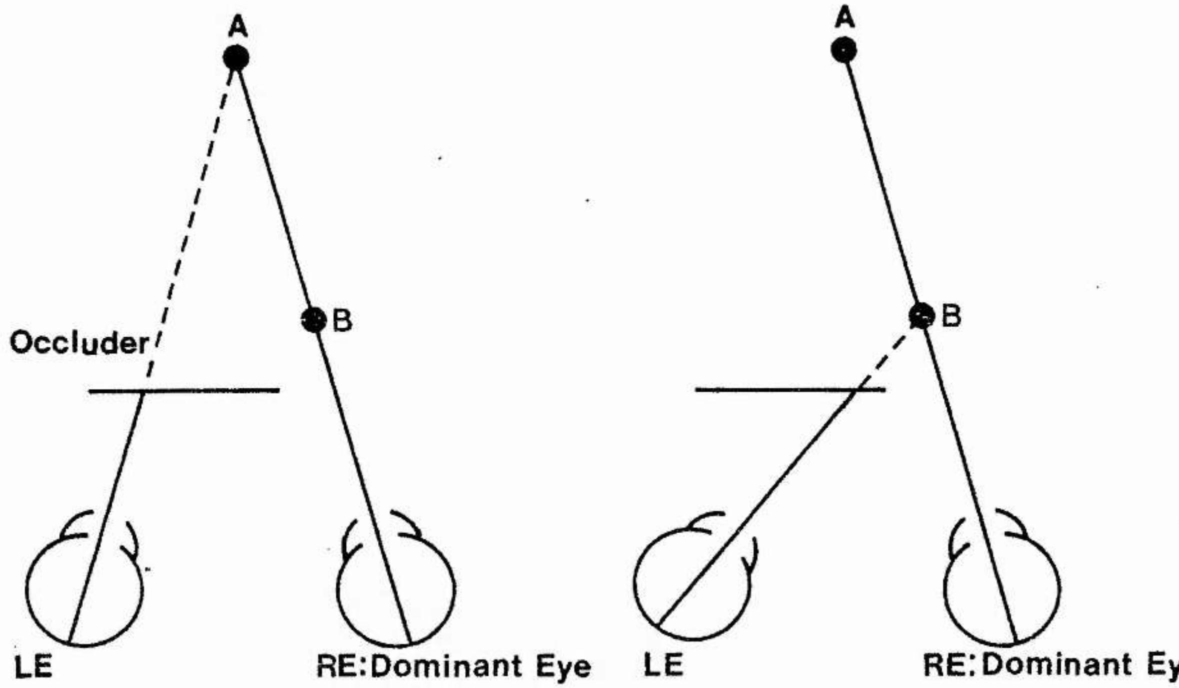
Walls places more emphasis on the motor components of dominance which are exemplified by the sighting tests. The visual direction of objects in space are judged solely by the dominant eye and it is the motor initiation record of the muscles of this eye that are monitored in order to judge the visual direction of objects. When two objects are aligned with one eye while the other is occluded and fixation is changed from one object to another there is a change in accommodative vergence. This is sometimes accompanied by apparent movement in the fronto-parallel plane (see Fig 1.5). Walls (1951) reported that apparent movement was seen only when one eye was covered and not when the other was covered. He formulated a theory that the efference signals to only one eye were monitored, the dominant sighting eye, and it was this eye that specified the directions of objects in space.

Walls's theory postulates that the egocentre is located in one eye (Walls, 1951; and also by other authors; Parson, 1924;Sheard, 1926; Rubin and Walls, 1969), and called the sighting eye. This contrasts with the principles of visual direction outlined above (Wells, 1792; Hering, 1879/1942, 1868/1977), that assume the egocentre is midway between the eyes (Compare Fig 1.5, 1.6). Other authors hold that the egocentre is located somewhere on the line joining the visual axes of the two eyes (Ogle, 1962; Ono, Wilkinson, Muter and Mitson, 1972;

Fig 1.6. Walls' (1951) Demonstration of apparent Movement experienced with one eye with a change in accommodative vergence with one eye occluded.

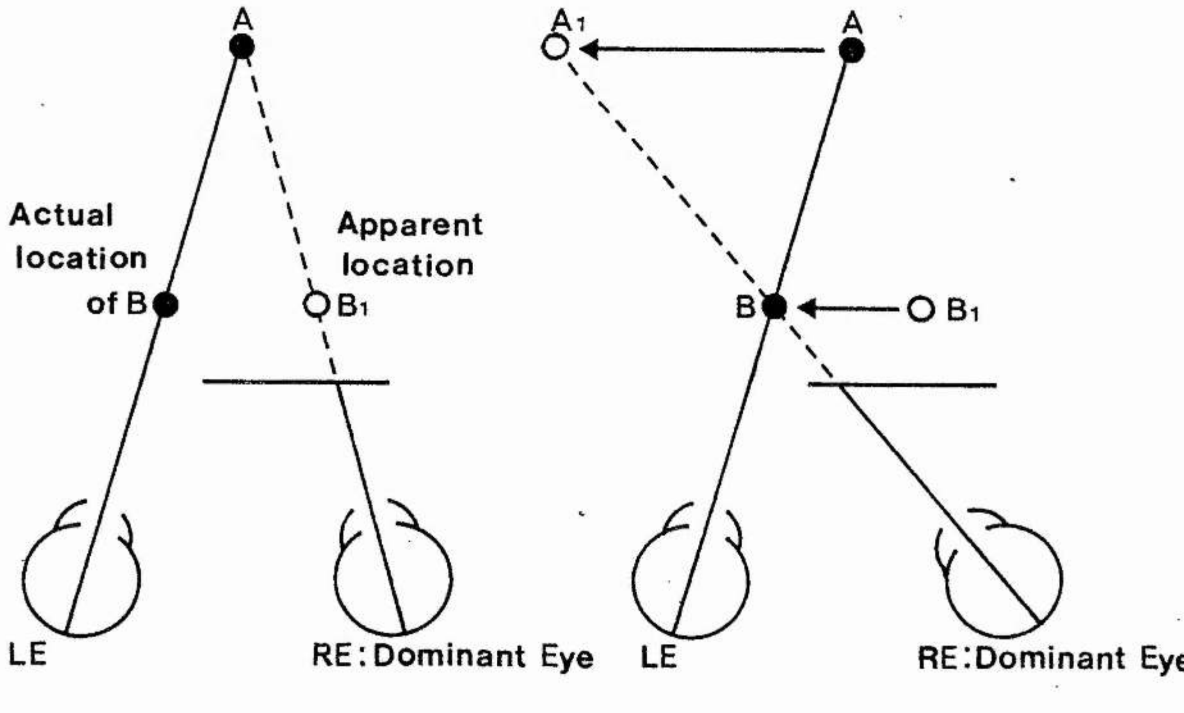
a) A and B aligned with the Right eye (sighting dominant eye) and Left eye occluded. No apparent movement of A is experienced (cf. Fig 1.5).

i)Fixation of A ii)Fixation of B



b) A and B aligned with the Left eye (non-dominant sighting eye). Right eye is occluded. Apparent movement of A to A1 and B1 to B is experienced to the left.

i)Fixation of A ii)Fixation of B



Barbeito, 1981).

The non-dominant eye in Walls's theory reduces the occurrence of diplopia by completing the convergence movement necessary to bring both images into register. Walls provides no experimental evidence for his theory apart from a description of the sighting process as shown in Fig 1.6. No mechanism or process was offered as to why the muscle innervations to only one eye were recorded at the expense of the other.

Sensory and motor aspects of dominance were believed to be two independent factors of eye dominance, the latter was considered more important because of the involvement with sighting dominance. This is a theme that has continued in the eye dominance literature. Binocular rivalry was not discussed at great length by Walls who believed it in no way related to the basis of sighting dominance.

1.3.2. Ogle's Theory of Ocular Dominance

Ogle (1962) outlined a similar hypothesis of ocular dominance as to that of Walls (1951). Again Ogle made the distinction between motor and sensory aspects of dominance, the motor aspect being responsible for stable vision. Location of objects are referred to the egocentric spatial directions of the dominant eye. The "local signs" ie. the location of the image on the retina of the dominant eye are monitored preferentially relative to the other eye. Two experiments were outlined to demonstrate this. One was based on Hering's experiment (involving changing fixation from a near to a far target with only one eye partially covered restricting the view of the far target) and the second on the presence of fixation disparity. Nine subjects participated in a preliminary study. Eight of these subjects showed movement of the far target when only one eye was covered and none when the other eye was covered. The eye covered in the condition when movement was experienced was designated the dominant eye and this agreed with the sighting dominance results for 5 of the subjects. Three subjects experienced smaller movements in both eyes and sighting dominance was mixed or not reported.

Fixation disparity was measured using a nonius alignment procedure. The nonius lines were surrounded by a square array of letters. One line for one eye was centred within the display and the other was adjusted to appear aligned with it. The line to the eye that was not centred within the square indicated which was the non-dominant eye. Results from a modified procedure were reported for nine subjects. Five of the subjects had a fixation disparity in one eye that was also the non-dominant eye on the Miles sighting test.

Ogle's theory is very similar to Walls's theory on ocular dominance and it will be referred to as the Walls-Ogle hypothesis.

1.3.3. Lederer's Classification of Eye Dominance Tests

Lederer (1961) presented a five category classification of ocular dominance tests based on a survey of tests in current usage. Unlike Walls, who specifies the independence of the "sensory" and "motor" tests, the interrelationships between the five classes are deemed to be obscure. The five classes are as follows; Class 1- monocular sighting and aiming, class 2- motor dominance of one eye in binocular vision, class 3- orientational dominance or position of the egocentre, class 4- sensory dominance and class 5- dominance of one half of the visual field. Lederer gives no indication to the possible underlying mechanisms. He concludes by saying,

> "It is obvious that the significance of ocular dominance is not by any means understood at present....Indeed, as has been shown above, the very definition and nature of ocular dominance remains as yet to be determined." (Lederer, 1961, page 573).

Gronwall and Sampson (1971) investigated the different classification procedures used by Lederer and Walls. Lederer used 5 classes and Walls emphasised the independence of two classes of dominance, motor and sensory dominance. Fifty students participated in a battery of seventeen tests and were classed as being right or left eye dominant on each test. The correlation coefficients between results from individual tests and groups of tests failed to confirm either classification procedure. The underlying assumption of the classification system of the two authors was that the mechanism or process responsible for the performance on the dominance tests within each group or class was the same but was independent of that of other groups or classes. It was not certain what the different tests were measuring and Gronwall and Sampson suggested that eye dominance reflects habitual use of one eye over the other in a range of tasks.

1.4. The Cyclopean eye vs the Sighting eye

The Walls-Ogle hypothesis makes a different prediction about the origin of visual direction in space to that of Hering (1879/1942) and Wells (1792). Ono, Wilkinson, Muter and Mitson (1972) replicated Walls's experiment with seven observers in a preliminary study (see Fig 1.6, using occlusion of one eye). Six subjects experienced apparent movement with both eyes and one subject with neither eye but no subject reported no movement with just one eye. This suggests that the egocentre is not located within one eye. Also the authors reported that the extent of the phorias in both eyes and the location of the egocentre determined the direction and extent of illusory movement when accommodative vergence was changed. It was suggested that the Walls-Ogle hypothesis could only be supported if the egocentre was located within one eye or if the phorias were asymmetrical. Nine subjects in their experiment reported apparent movement in both eyes and given that the majority of subjects have a sighting eye (Rubin and Walls, 1969) the authors (Ono et al, 1972) concluded that subjects who report apparent movement in only one eye should be rare.

However, some authors have suggested that the egocentre is eccentrically located and in the sighting dominant eye (Pickwell, 1972, 1973; Collinge, 1979). Pickwell (1972) suggested that the egocentre may be located nearer the sighting eye. Other researchers have measured the egocentre and compared predictions from this with performance on a variety of visual tasks.

1.4.1. Measurement of the Egocentre

Four methods of measurement of the egocentre have been commonly used in the literature. However, several of these have been modified and are described below (Ono et al, 1972; Mitson, Ono and Barbeito, 1976).

1). The Howard and Templeton (1966) modified method (Mitson et al, 1976): requires the subject to look at two alternating lights at different distances from the subject. The near light is adjusted such that the imaginary axis is pointing at the self. Diplopia is not experienced and pointing is not involved. The point of intersection of the axes for different directions of the two lights is the egocentre.

2). The Funaishi modified method (Mitson et al, 1976): requires the subject to point to several successively fixated targets in the same fronto-parallel plane with respect to the self. The alignment is made to one fixation point with the finger at one distance and then at another distance. A line joining the finger positions is extended back to the subject and the egocentre is where the lines from all the fixated points intersect. The hand is not seen and neither is diplopia.

3). The modified Roelof method (Barbeito and Ono, 1979): requires the subject to fixate a point at the intersection of two lines coincident with lines of sight of each eye. A third illusory line is perceived pointing to the egocentre. Subjects indicate a point on this illusory line but the hand is not seen. This is repeated for different directions and the egocentre is the point of intersection of the set of lines which join the fixation points with the finger positions.

4). The Fry method: requires subjects to fixate the further of the two stimuli and to locate by pointing to the location of the diplopic images of the near target. The hand is not visible to the subject. The egocentre is located according to Hering's principles of visual direction that specifies the relationship between the location of the fixation point, the location of the double images and the egocentre (see Fig 1.4, page 11)

The last two methods do not require a reference to the self and do involve pointing responses. In a similar way several of the sighting tests require a localisation response although the hand is seen and feedback is possible in order to make the correct alignment. However, both these egocentric methods result in greater variability due to pointing errors (Barbeito and Ono, 1979).

The Funaishi and Howard and Templeton methods require a reference to the self although the former requires a pointing response. There is a low correlation between the measures derived from the two methods (Barbeito and Ono, 1979) and it has been suggested that the Funaishi method is measuring a kinaesthetic egocentre and the Howard and Templeton method is measuring the visual egocentre (Howard and Templeton, 1966).

Barbeito and Ono (1979) compared the predictions from these methods to results from three visual localisation tasks; i) judging the straight ahead ii) setting a marker at a distance between two other points at another distance to bisect the angle formed by the visual directions of these two and iii) judging the extent of apparent movement of visual targets during accommodative vergence. The Howard and Templeton method successfully predicted performance on these tasks. This suggests that the judgement of visual directions is related with reference to the self and involves purely visual judgements. Many of the sighting tests involve pointing responses and it would not be expected that there would be close agreement between the Howard and Templeton method and sighting results (Barbeito, 1981).

The sighting or alignment tests require that both eyes remain open. Walls (1951) demonstrated the sighting eye hypothesis by occluding or partially occluding one eye. Sighting along a rod and aiming the rod to the self with one eye open results in very similar positions of the rod. However, if both eyes remain open the rod position will tend to point to the nose for the latter condition but may be directed at one eye for a sighting position. It has been suggested that Walls may have confused these two points and led him to believe that it was the dominant sighting eye that was also the egocentre (Howard, 1982).

However, the cyclopean hypothesis makes different predictions to that of the sighting eye hypothesis for judgements of visual directions in sighting tasks. The role of the egocentre and principles of visual direction will be examined below.

1.5. Experimental Studies on the Egocentre and Sighting Behaviour

The location of the cyclopean eye or egocentre has been reported to covary with the sighting eye (Francis and Harwood, 1951; Barbeito, 1981) and visual direction also covaries with the eccentricity of the cyclopean eye (Ono, Wilkinson, Muter and Mitson, 1972; Barbeito and Ono, 1979).

Barbeito (1981) measured the position of the egocentre using the Howard and Templeton method and measured the sighting dominance using the hole in the card method and the point test. The sighting dominant eye was found to be on the same side as the egocentre for 19 of the 20 subjects. There was a difference between the two sighting tests; the mean position of the finger did not correlate significantly with the position of the egocentre whereas the hole position did confirm this position. When visual feedback was eliminated by covering the hole and eliminating the view of the finger, subjects made judgements displaced to the midline on a line joining the cyclopean eye and the target was not on the visual line of one eye or the other.

Barbeito (1981) concluded that it is the egocentre that determines which eye will be used to sight with in an alignment test and be classed as the dominant eye. It is the nature of the alignment tests that forces "monocular" viewing giving the impression that one eye is specifying visual directions. The eye chosen to sight with is the one nearer the egocentre.

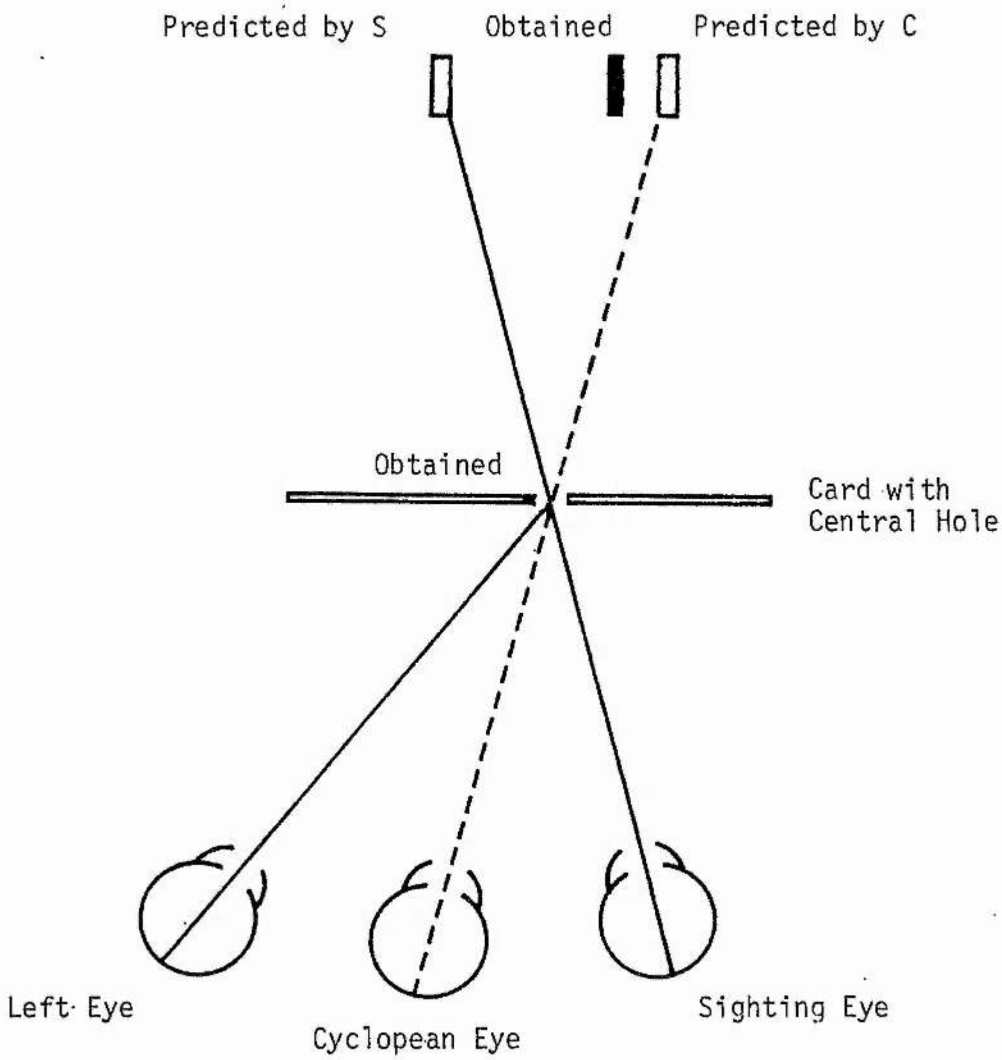
Ono and Barbeito (1982) carried out a series of experiments using the hole in the card test to test the competing sighting and the cyclopean eye hypotheses for the centre of visual directions. The results confirmed the predictions from the cyclopean eye hypothesis. Fig 1.7 shows the predicted results from the competing hypotheses and the obtained results. Therefore, the cyclopean eye does appear to be a valid feature of binocular space perception and sighting behaviour. (It is the nature of the sighting tests that imposes monocular viewing or sighting). It is probable that in some subjects the egocentre is eccentrically located which may account for the reported high consistency of the sighting eye (Porac and Coren, 1981). Barbeito's (1981) study also suggested that this is a possibility. Some subjects have been reported to be unable to perform sighting dominance tests and the egocentre is assumed to be at the midpoint between the eyes (Pickwell, 1972; Barbeito, 1981).

1.5.1. Asymmetrical Position of the Egocentre

It is possible that sensory differences between the eyes affect the position of the egocentre. If a neutral density filter is placed before

Fig 1.7 Predicted Results from the Hole in the Card Sighting Test from i) The Cyclopean Eye Hypothesis (C), ii) The Sighting Eye Hypothesis (S). Obtained Results from 12 Subjects (taken from Ono and Barbeito, 1982).

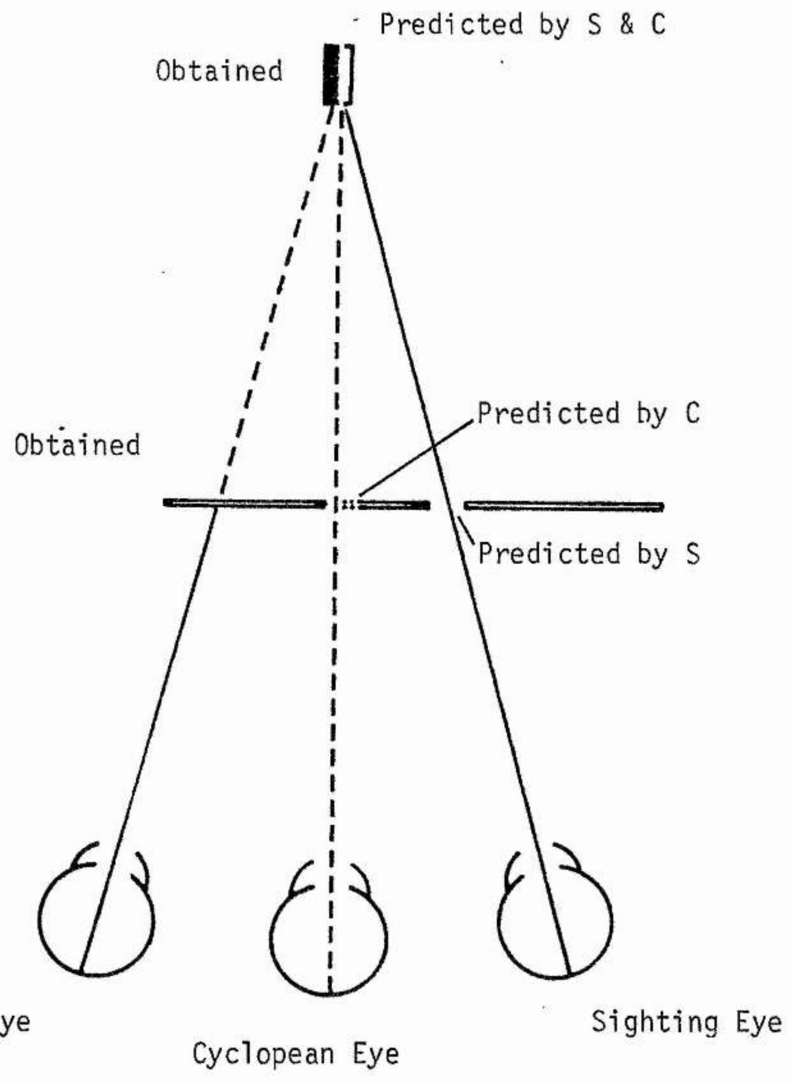
a) Fixating the Aperture



(continued)

Fig 1.7 continued

b) Fixating the Target



one eye the external position of objects are shifted towards the contralateral eye (Diehl, 1942; Francis and Harwood, 1951). Denser neutral density filters were required before the dominant eye for an equivalent shift made with the other eye.

Data collected by Church (1970) suggests that two year old children do not show any eye preference or sighting behaviour. By the age of three, a preference develops and becomes more stable by school age (Dziadosz and Schaller, 1977). It is possible that this time period may coincide with a period of critical development of the visual system. The presence of a critical sensory period in humans has not been firmly established, although there is a common clinical belief that early visual loss (eg. in strabismus) can never later be remedied by treatment. Hohmann and Creutzfeldt (1975) measured the tilt aftereffect in strabismic children and reported some correlation between late onset of the deviation, amount of transferred aftereffect and ophthalmological assessment of binocularity. It is possible that slight misalignment or a performance asymmetry during this critical period may change the location of the egocentre. If one eye becomes suppressed during development because of the misalignment of the visual axes, the normal relation between object location, retinal location and eye posture may not develop. Direction of objects in space would be made with reference to the dominant non-suppressed eye that would have extracted this information (Mann, Hein and Diamond, 1979). Less dramatic performance differences may have changed the location of the egocentre.

Sighting dominance has received most attention in the literature and will be discussed below in relation to other visual features of binocular vision.

1.6. Sighting Dominance: motor aspects

Several investigators believe sighting dominance involves a motor component which is related to eye movement performance (Schoen and Scofield, 1935; Walls, 1951; Lederer, 1961; Ogle, 1962; Porac and Coren, 1976). The sighting dominant eye has been reported to i) fixate more accurately (Sheard, 1925), ii) has greater fixation stability (Schoen and Scofield, 1935), iii) performs more accurate eye movements (Clark, 1935), iv) recovers the state of fixation faster and v) converges faster

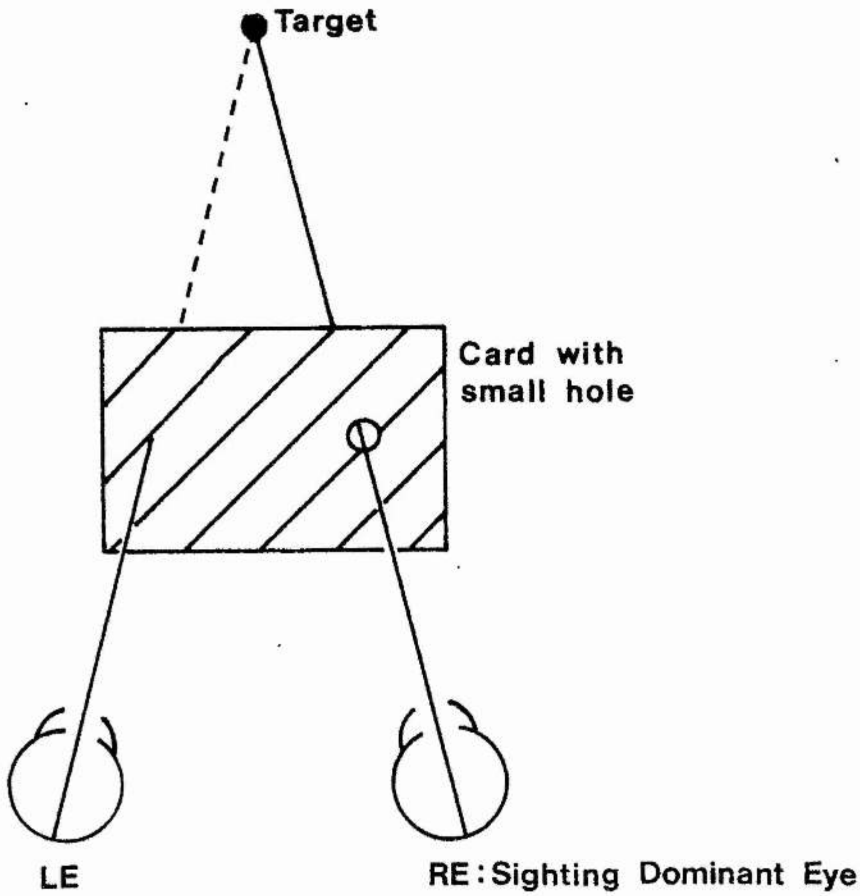
(Crider, 1935). The non-dominant eye performs eye movement execution at a slower rate, completes fusion and thereby maintains single vision and is less stable in maintaining convergence and may possibly develop a fixation disparity (Ogle, 1962).

Schoen and Scofield (1935) investigated the neuromuscular efficiency of the two eyes in binocular vision. Diplopia thresholds of the two eyes were measured by introducing a prism (base-apex axis horizontal and base nasal) before one eye while both eyes fixated a point 9 feet away. The power of the prism had to be greater before the non-dominant eye (as measured by the point test) before single vision broke down compared to that before the dominant eye. This did not reach significance. In a second experiment each eye was independently measured for the time required for single vision to be re-established after the removal of a base-out prism resulting in over-convergence. The non-dominant eye re-established single vision after this interference quicker than the dominant eye. It was concluded that the non-dominant eye had greater neuromuscular efficiency and greater diplopic reserves than the dominant eye. However, it is not certain if in normal binocular vision the function of the two eyes would differ in this way.

In an experiment reported by Money (1972) eye movements were recorded while a display was scanned in a visual search task. The non-dominant eye (as defined by two pointing tests) took longer than the dominant eye to scan the display. However, eye movement recordings were monocular and it is not certain if in a binocular viewing situation there would be a time differential between the eyes and/or a performance difference in the percentages correct.

However, the emphasis on the motor aspects of sighting dominance has tended to obscure other aspects of the sighting task. With the hole in the card test, one eye sights the target through the hole while the other sees the texture of the card (see Fig 1.8). It is possible that rivalry may occur between the two images and also between the diplopic images of one of the targets in the alignment test. Therefore, it is misleading to assume that sighting tests are testing an ocular-motor process. It has already been shown that both eyes are involved in specifying visual directions together with the egocentre. It is more meaningful to investigate the functioning of the two eyes in binocular

Fig 1.8. Diagram to Demonstrate the Hole in the Card Sighting Test: sensory factors as well as oculomotor factors may be involved.



Subject sights the object through the hole with the right eye. The left eye sees the textured card.

vision or a dichoptic viewing task and to investigate the contribution of each eye to the binocular percept.

1.6.1. Ocular Dominance: sensory aspects

Several investigators believe that sensory dominance which usually takes the form of binocular rivalry, is independent from motor dominance (Walls, 1951; Lederer, 1961; Ogle, 1962). Binocular rivalry tests of dominance have been neglected in the literature partly because of the difficulty in administering such tests (Walls, 1951) and because they have been assumed to be statistically unreliable (Ogle, 1962).

However, rivalry has been assumed to reflect a competition between the eyes and dominance is believed to be the superiority of one eye over the other. Several investigators adopted certain criteria for judging if one eye was dominant. If one image of a rivalrous pair was registered as being visible for a time 20% greater than the other, it was classed as the dominant eye, (Washburn, Faison and Scott, 1934; Gronwall and Sampson, 1971). A two switch key procedure was used, one key to record the duration the left image was visible and one to record the duration the right image was visible. Composites or combinations of the two images were not considered a valid category of perception.

An attempt to develop an objective measure of ocular dominance using rivalry was made by Enoksson (1963) using optokinetic nystagmus. If both eyes view a moving pattern from right to left, both eyes show nystagmic eye movements in a right to left direction and vice versa for a left to right moving pattern. If the eyes are given patterns moving in opposite directions there is clear phenomenal rivalry. The eye movements become yoked to the direction of pattern movement that is phenomenally present ie. dominant. Enoksson (1963) reported that only eight out of thirty of his subjects showed dominance. However, he only recorded dominance if the subject showed nystagmic eye movements of the same direction throughout the 2 minute observation period. It is not possible from his data to know if subjects did show varying degrees of rivalry, nor did he record subjective rivalry reports.

There are wide individual differences in the amount of rivalry dominance found (Wade, 1975a, 1976b) suggesting that the direction and degree of dominance can be derived from a rivalry test rather than using a dichotomous classification . There are several lines of evidence that suggest rivalry is not an extension of the eye competitive approach first adopted in the eye dominance literature. Washburn et al, (1934) reported in her experiments that composites were seen quite frequently during rivalry observation. Enoksson (1963) also noted that colours and pattern configurations of a rivalrous pair of stimuli rivalled at different rates and not in synchrony. Hamburger (1949) studied binocular rivalry extensively in 49 subjects and reported that in the stamp test (two stamps of different colours and detail are presented one to each eye) different features rivalled independently of others. Numerals did not fluctuate at the same rate as the colours and the periphery rivalled at a different rate from the centre of the stamps. Creed (1935) reported a similar finding, again using stamps as stimuli.

The term dominance to describe the asymmetry in rivalry carries with it the connotation of competition between the eyes and that binocular vision is at any one time effectively monocular. However, the above studies demonstrate that rivalry may occur in a piecemeal fashion over the two retinae and does not involve one whole retina suppressing another.

1.7. Binocular Vision and Suppression

When discrepant images are presented one to each retina on corresponding areas phenomenal rivalry occurs characterised by alternating phases of dominance and suppression. The alternating phenomenal suppression and dominance has been claimed to be an expression of the same underlying process as found with single vision during apparent fusion of similar images (Porta, 1593; Du Tour, 1760; Verhoeff, 1935; Asher, 1953; Hochberg, 1964; Kaufman, 1964; Levelt, 1968). Diplopia is rarely experienced in normal viewing conditions suggesting some form of suppression may be occurring. Eye dominance has been viewed as one process in which to reduce the occurrence of diplopia in normal vision (Miles, 1929). Diplopia is also experienced in the simple alignment test. Hughes (1953) suggested that the neuromuscular performance of the two eyes differed. In binocular vision the non-dominant eye (sighting eye) took longer to complete fusion and in order to preserve single vision it was suppressed.

This suggests that sensory and motor processes in dominance cannot be easily differentiated as has been assumed. However, investigators have still been concerned with the relation between sighting and rivalry dominance tests using the dichotomous classification.

Washburn, Faison and Scott (1934) reported that only a third of their subjects had a rivalrous dominant eye that was also the dominant eye in a sighting test. Coren and Kaplan (1973) concluded from the results of a correlational study that rivalry and sighting dominance were independent. The same authors later reported a close relationship between the two (Porac and Coren, 1978). Sixteen out of twenty four subjects in a study by Wade (1976a) had a rivalrous dominant eye that was also the dominant eye in a sighting test .

The relation between the two types of tests is not clear. A further variation on the rivalry test was reported by Humphiss (1969). He found that if a red filter was placed before the good eye of an amblyopic subject a refraction chart viewed with both eyes open, appeared a dull red. A similar procedure with a binocularly normal subject produces no such effect unless a +3D lens was placed in front of the non-filtered eye. This suggests that some form of interocular suppression is occurring and only when this is reduced by filtering one eye does one eye become dominant. Humphiss (1969) recorded the value of the plus lens required in front of each eye for the binocular view to turn red. If the values were different in the two eyes, a measure of sensory dominance was derived. This suggests that rivalry dominance may be a reflection of asymmetrical interocular suppression between the eyes.

If one rivalrous image has a greater number of contours than the other it will be seen a greater percentage of the viewing time than the other (Breese, 1899). By changing the strength of a rivalrous stimulus, eye dominance effects can be mimicked. If the mechanism of binocular rivalry is investigated further it may provide a further understanding of the role of rivalry dominance in binocular vision or the possible sensory/motor factors that may be responsible for ocular dominance.

1.7.1. Binocular Rivalry

Several methods have been used to study the role of suppression in apparent fusion and single vision. First, the displacement of images during fusion: the fused binocular percept appears intermediate to the two values of both images although according to the suppression theorists it is due to fixation disparity accompanied by suppression (Ogle, 1964). Second, by investigating the spatial and temporal properties of fusion and suppression it would be possible to discover the nature of the process underlying single vision (Kaufman, 1963; Crovitz and Lockhead, 1967; Collins and Blackwell, 1974). Third, presentation of test probes can monitor the threshold sensitivity of the image. It has been reported that the threshold sensitivity as measured by the test probe technique is reduced by up to 0.5 log units during rivalry suppression (Wales and Fox, 1970; Fox and Check, 1972; Blake and Camisa, 1979). The test probe is presented during phenomenal rivalry and the threshold sensitivity can be monitored for the dominant and suppression phases.

A similar procedure has been used during apparent fusion and if sensitivity is reduced it is assumed that suppression is occurring. However, results from this technique have been mixed (Fox and Check, 1966; Fox and McIntyre, 1967; Makous and Sanders, 1978) and reports of the reduced sensitivity during the rivalrous suppression phases has also been questioned (Hollins and Bailey, 1981; Cogan, 1982). Individuals who have had no previous history of clinical optical abnormalities have been reported to show continuous dominance of one eye during apparent fusion (Sanders, 1980). This is similar to the findings of Schor (1977, 1978) who reported strabismic subjects exhibited rivalry with discrepant images but showed continuous dominance of one eye while viewing two similar patterns dichoptically.

Binocular rivalry will be discussed in the following sections with reference to the proposed mechanisms involved in the alternating phases of dominance and suppression. The aim is to discover a possible process that may explain the asymmetry reports in rivalry dominance tests.

1.7.2. Inhibitory Interactions

A model of reciprocal inhibition has been postulated to account for the effects of binocular rivalry (Abadi, 1976; Wade, 1978a). Two channels, one sensitive to each eye undergo interocular suppression and the alternating phases of dominance and suppression are believed to occur by a process of selective adaptation. The dominant stimulus is determined by the channel active at that time which inhibits the other channel. The active channel undergoes adaptation and becomes less active releasing the previously inhibited channel. During the suppressive phase it recovers from adaptation (Crovitz and Lockhead, 1967). Hering was one of the original proponents of reciprocal inhibition (Hering, 1874/1964).

Wade (1974) also reported that rivalry suppression was orientationally selective. This would be predicted from a reciprocal inhibition model involving inhibition between populations of feature detectors tuned to different orientations and spatial frequencies. The pattern of the dominance and suppression durations varied with the orientations of the gratings used, vertical gratings were visible for longer than gratings oriented at 45 degrees and the results were interpreted as support for the cortical localisation of these effects. O'Shea and Crassini (1981a) using a reaction time and forced choice technique reported that suppression was not acting like a blanket effect on all orientations of gratings but was selective. Changing a rivalrous grating during the suppressive phase from one orientation to another did not change the rivalrous state if this orientation stimulated a population of units outside the tuning and inhibitory influence of the original population of units responsive to the suppressed rivalrous grating. However, a grating at an orientation within this range did change the state to one of dominance. Abadi (1976) holds that binocular rivalry involves lateral inhibition between different feature detectors.

Eye dominance as realised in binocular rivalry can be accommodated within this model by assuming asymmetrical inhibitory connections between the two channels. It is also possible that the eyes show a differential in threshold sensitivity that may be investigated using the threshold sensitivity test probe technique. This may demonstrate a difference in the depths of suppression.

Studies that have used the test probe technique have usually presented the probe to one eye in an induced state of continuous dominance (Blake and Lema, 1978; Blake and Camisa, 1979, both had the left eye in a dominant state; Hollins and Bailey, 1981 had the right eye as dominant). Wales and Fox (1970) used both eyes and reported an asymmetry in the proportion of correct detections of the probe between the two eyes. Subject JR showed an increased rate of detection above the baseline detection rate of 75% for the left eye in the experiments but not for the right eye. Cogan and Silverman (1980) also reported eye dominance effects in detection rates. Detection rates for the location of flashes were the same for both eyes under monocular testing. In conditions of rivalry and fusion (both fields uniform grey) the detection rates differed, the rate being higher for the dominant (acuity dominance) eye. The authors suggested dominance was a manifestation of a contrast sensitivity difference in binocular vision.

However, some evidence against a reciprocal inhibitory model has been reported. According to the model the depth of suppression during the suppressive phase of a stimulus should decrease from the initiation of suppression to the time immediately preceding dominance, because of the changing inhibitory levels during adaptation. Fox and Check (1972) using the test probe technique found that the recognition threshold was raised by equal amounts throughout the suppressive phase. Some investigators have suggested that the depth of suppression and the time course of suppression reflect different aspects of the same phenomenon (Blake and Camisa, 1979; Hollins and Bailey, 1981), which would not be expected from a reciprocal inhibition model.

The reciprocal-inhibition model implies that rivalry is a "contest" between the eyes which would support some of the early theoretical views of single vision in binocular perception. The methodology adopted for recording rivalry has supported the notion of a competition between two monocular channels. Usually only two switch keys are present to record the perception of each whole image.

However, there is sufficient evidence to suggest that rivalry is not merely a competition between the two eyes. Wade (1974) found that composites occupied 36% of the observation period for real image rivalrous gratings. Similarly, Hollins and Bailey (1981) reported that 60% of the viewing time was of composites. It would appear that composites are a valid category possibly representing an intermediate state of suppression (Hollins and Leung, 1978; Hollins, 1980). Ogle and Wakefield (1967) reported that black and white rivalrous images appeared as lustre for some of the time suggesting an intermediate form of suppression.

The reciprocal-inhibition model cannot account for all the evidence regarding rivalry and it is unlikely that one eye's image rivals as a whole with the other. It has been reported that rivalry alternation rates can be modified if one aspect of the image is changed. Creed (1935) using stamps reported that if the colour is made identical, the rate of rivalry of the form or shapes on the stamps decreased. Few studies have reported the effects of rivalrous stimuli with identical surrounds. Makous and Sanders (1978) used a test probe technique, the probes were presented to the centres of grating displays that had either rivalrous centres and identical surrounds, or identical centres and rivalrous surrounds. The detectability of the test flash presented in identical fused centres varied with the phase of dominance of the surrounds. The authors did not investigate the rate of rivalry of the centre rivalrous gratings when alone and when surrounded by identical gratings. It would be interesting to investigate the area and type of influence the adjacent rivalling contours had on the state of the stimuli.

Binocular rivalry probably reflects an inhibitory process but its exact mechanism has not yet been elucidated. Evidence against reciprocal inhibition has been given by Levelt (1966). He found in a series of experiments that the mean dominance duration of the stimulus in one eye was independent of the stimulus strength, and the duration was dependent on the stimulus strength of the contralateral eye. Dominance durations were unaffected if the stimulus strength was increased but the time that that stimulus remained suppressed was reduced. Thus a change in dominance depended on the properties of the non-dominant stimulus, an increase in strength of this stimulus shifted the dominance phase to one of suppression. Walker (1975) found that the course of rivalry was sensitive to a change in the strength of the suppressed but not the dominant stimulus. Support for this view has also been reported by O'Shea and Crassini (1981a) and Blake and Fox (1974a), data re-analysed by Walker (1978). This suggests that suppression during rivalry is not a blocking effect of one channel (Blake and Fox, 1974a) but represents incomplete suppression and the phases remain sensitive to changes in the stimulus features.

It is probable that rivalry reflects a piecemeal suppression of local areas on different corresponding areas of the two retinae such that one area in the image will be dominant while neighbouring areas of the same image are suppressed (Meenes, 1930).

1.7.3. The Site of Binocular Rivalry

Psychophysical techniques have been used to determine the stages of visual processing within the visual system at either peripheral or central levels. Central processing is often assumed to reflect binocular analysis that occurs at or beyond the site of convergence of the two monocular inputs.

Binocular rivalry does not appear to prevent stimuli being analysed that are dependent on binocular processes. A phenomenally suppressed eye can still contribute to stereopsis, and depth is reported to be stable despite on going alternations of dominance and suppression of the two images (Kaufman, 1964, 1974; Julesz and Miller, 1975; Blake, Westendorf and Overton, 1980). This suggests that rivalry is not having a blanket suppressive effect. Other investigators have suggested that binocular rivalry occurs after the processing site of visual effects that are reliant on binocular channels.

Several aftereffects are assumed to be analysed centrally (Sekuler, 1974). These aftereffects also exhibit interocular transfer. Adaptation to a visual stimulus can occur even though the adapting eye is phenomenally suppressed by a pattern in the other eye. The aftereffect is just as marked as the aftereffect measured when the adapting stimulus is viewed without rivalry. Similarly, the aftereffect will transfer interocularly despite phenomenal suppression or rivalry during the adapting phase. This has been reported for several visual aftereffects; for adaptation to movement (Lehmkuhle and Fox, 1975a; O'Shea and Crassini, 1981b), adaptation to tilt (Wade and Wenderoth, 1978) and for the spatial frequency shift and threshold elevation of contrast (Blake and Fox, 1974b). If suppression were blocking the adapting stimulus it would be expected that no aftereffect would be generated. The above results have been interpreted as evidence of rivalry suppression occurring at or beyond the convergence of the two inputs of the eyes. Also adaptation to the rivalrous stimulus reduced the overall duration of time the stimulus was reported as visible over the observation period and rivalry was inferred to occur after the site of adaptation (Blake and Overton, 1979).

However, the above studies assume serial processing (Sekuler, 1974). Ramachandran (1975) reported that apparent movement was suppressed during rivalry and suggested motion, rivalry and depth may be processed by parallel channels.

Given that rivalry suppression may occur after the convergence of the two monocular channels rivalry dominance may reflect some asymmetrical inhibitory process in binocular as well as in monocular channels.

1.7.4. A Continuum of Suppression in Binocular Vision

Diplopic images are not readily experienced in normal binocular viewing situations. Kaufman (1963) found the maximum effect of complete suppression occurred in the fovea which corresponded to the size of the fusion areas ie Panum's fusional areas. It has been reported that subjects with misaligned visual axes have suppression in the foveal areas and not in the peripheral areas (Siretaenu and Fronius, 1981). This suggests that suppression may be crucial for single vision when more acute processing is involved.

Several investigators believe that there is a continuum of suppression, at one end constant suppression as in clinical cases of strabismus to temporary suppression as may occur with sighting behaviour and rivalry suppression that may also occur in normal vision at the other (Porac and Coren, 1975, 1978). The temporary suppression in rivalry is believed to involve the same process as that in long term or constant suppression (Blake and Lehmkuhle, 1976; Wade, 1976a). Ocular dominance may be an expression of this continuum and individuals therefore would be expected to show varying degrees of suppression in the binocular rivalry procedure.

Visual acuity can be greatly reduced in one eye (ie amblyopia) if the eyes are misaligned as in strabismus early in life or due to severe uncorrected refracted error in one eye (anisometropic amblyopia). For these individuals to function with both eyes open one eye is suppressed (the turned eye) in order to reduce diplopia caused by similar images falling on non-corresponding places and confusion of dissimilar images falling on corresponding places. Suppression is usually accompanied by reduced binocular functioning such as stereopsis (Duke-Elder, 1973). The acuity loss is restricted to foveal areas and is equal for the two eyes outside these areas (Siretaenu and Fronius, 1981; Hess, Campbell and Zimmern, 1980). Misalignment of the visual axes causes a mismatch of the corresponding regions but because of the reduced acuity in the peripheral areas suppression will only be restricted to the foveal areas. A study by Siretaenu and Fronius (1981) showed that regions of acuity loss were also areas of deep interocular suppression. In the peripheral areas where there was no marked interocular suppression, binocular summation and interocular transfer could be demonstrated (Siretaenu, Fronius and Singer, 1981). An aetiology of suppression was suggested to account for these findings. Early in life a small mismatch between corresponding areas due to a small angle squint is not crucial because the fusion ranges are large. But diplopia occurs as these areas shrink with age. Binocular rivalry occurs with a dominance bias towards the non squinting eye. This becomes long term suppression which disrupts the central pathways resulting in visual impairment. In a similar vein, less critical misalignment of one eye or a difference in optical performance may influence or bias the pattern of binocular rivalry such that one eye becomes dominant. This may be reflected in asymmetrical inhibition between the eyes.

1.7.5. Neurophysiological Studies

Manipulation of the visual input during the sensitive period of visual development of cats and monkeys have altered the neuronal sensitivities and connections as found by micro-electrode recordings. Induced artificial squint, alternating monocular occlusion reduces the complement of binocular cells in the visual cortex areas 17 and 18 (Hubel and Wiesel,1965). This occurred for all the visual field and did not result in amblyopia. Maffei and Bisti (1976) reported disruption of cortical binocularity for kittens reared in total darkness with the extra-ocular muscles cut suggesting that disruption to the cortex was not necessarily due to discordant visual input. This suggests a new interpretation on strabismus. However, evidence of suppression with this manipulation is lacking.

Optically induced squint without the misalignment of the visual axes carried out in other studies also changed the ocular dominance categories. The amount of change depended on the direction and strength of the prism (Smith, Bennett, Harwerth and Crawford, 1979). Changes in the neurophysiology of the cortex has resulted in concomitant behavioural changes. Animals reared with alternating monocular occlusion were unable to use stereoscopic depth cues (Blake and Hirsch, 1975). With monocular closure, the neurones in the visual cortex become dominated by the non-deprived eye (Wiesel and Hubel, 1963) although there have been no reports of accompanying suppression. Such studies have been concerned with the loss of binocular neurones and not with asymmetrical performance of the eyes in binocular vision.

Abnormalities in visual input during the critical sensory period in animals have a profound effect on the functioning of the visual system. Abnormal visual experience in humans such as squint can result in similar behavioural deficits eg stereoblindness as reported in the animal studies above (Banks, Aslin and Letsin, 1975). However, care must be taken when analogies are drawn between changes in the neuronal population found with micro-electrode techniques and associated behavioural deficits in animals to the anomalies found in human visual performance.

Levi, Harwerth and Smith (1979) used a dichoptic suprathreshold masking paradigm and from the results concluded that stereoblind individuals may lack excitatory connections but still retain inhibitory connections. Similarly, stereoblind individuals do show rivalry (Schor, 1978; Westendorf, Langston, Chambers and Allegretti, 1978) suggesting that early abnormal visual experience as with strabismus may differentially affect binocular connections leaving some intact while others eg. those responsible for stereopsis, are disrupted.

It is possible to conceptualise eye dominance in terms of asymmetrical connections between binocular and monocular units differentially driven by the two eyes. However, it would not explain the asymmetries in performance of the two eyes found on the different tests of dominance with rivalry and sighting.

1.7.6. Eye Movements and Binocular Rivalry

Kaufman (1963) reported that the spread of suppression in binocular rivalry was related to non-conjugate eye movements. Suppression was found to be greater for an horizontal bar than a vertical bar as non-conjugate horizontal eye movements would cause the vertical bar to slide over the retina and stimulate a greater number of receptors and keep it visible for longer. Only the two ends of the horizontal bar would stimulate new receptors. The sliding vertical contour is believed to leave a wake of suppression across the horizontal bar in the contralateral field. Wade (1975a) reported dominance measures with real image rivalry derived from the overall durations the left and right eye stimuli were visible and expressed this as a ratio. These differences were more marked when vertical lines were presented to the dominant eye. It was suggested that eye movements were responsible for the dominance effects. Wade (1974, 1975a) found a difference in durations the right and left eye's images were reported to be visible for real image rivalry but not for afterimage rivalry. With the latter procedure (Wade, 1975a) there was very little difference between the durations that each eye's image was visible. These equal durations found with the afterimages are believed to reflect almost equal interocular suppression between the eyes. Therefore, dominance as found with real images may be due to peripheral factors such as eye movements that change the strength of that stimulus rather than asymmetrical inhibition. However, Hollins and Bailey (1980) recorded rivalry with 2 degree diameter gratings, one of which was vertical and found no effect of orientation on the total durations each image was visible.

Wade (1978b) put forward an hypothesis of eye dominance, to explain the discrepancies reported between sighting dominance and rivalry dominance, based on eye movement factors. This is discussed in Part II, chapter 2.

Levelt (1966, 1967) suggested that the main role of eye movements in rivalry was to restore the suppressed image to dominance. Sabrin and Kertesz (1980) measured eye movements of 4' of arc while subjects viewed ring-disc rivalrous stimuli and non-rivalrous stimuli. Fifty percent more micro-saccades were recorded during rivalry compared to non-rivalry. The dominant eye (as defined by the report of a longer overall duration of dominance) had a greater proportion of microsaccadic activity during phases of phenomenal dominance as well as suppression relative to the non-dominant eye. The authors suggested that a gain mechanism in the oculomotor system may be responsible. Microsaccadic activity also showed a decreasing rate during the suppressive phase suggesting that suppression may decrease in depth over this phase which contrasts with the conclusions drawn from the results from the test-probe studies (Fox and Check, 1972).

It is possible that factors such as eye movement differences between the eyes can account for the rivalry dominance effects. However, the majority of studies that have investigated eye dominance have compared the monocular performance of each eye on a task or have monitored the sensitivity of only one eye during a binocular viewing situation. Rivalry dominance does involve a dichoptic viewing situation but the procedure of measuring dominance and the classification of the results has been influenced by the earlier views on dominance : one eye is seen as contesting with the other. The question is;- Is eye dominance realised in a normal binocular viewing situation?, and if so, what binocular interactions are responsible for its effect? If one eye contributes more to the binocular percept than the other what is the nature of this contribution and type of interaction?

The following section looks at those studies that have reported ocular dominance effects using binocular viewing paradigms. Several of the studies report dominance effects as an observation from the main research theme. There have been no systematic studies of dominance using the dichoptic and binocular viewing paradigms.

1.8. Binocular Viewing Paradigms and Ocular Dominance

Studies investigating binocular visual interactions can be divided into two areas. One, studies dealing with single vision and stereopsis and two, those concerned with how stimuli presented to one eye affect the appearance of stimuli presented to the other which includes areas such as masking, summation and other dichoptic viewing paradigms. If two images are presented stereoscopically they are seen single lying in a central position of the visual field intermediate of the position of the two monocular stimuli. Although this has been taken by the fusion theorists as evidence for fusion, Kaufman (1974) argues this can equally occur with fixation disparity and suppression of one image. To overcome the problem of fixation disparity Ono, Angus and Gregor (1977) presented disparate stimuli for 100 msec together with nonius alignment and recorded the occurrence of apparent fusion and/or suppression. The overall results of their study showed that fusion or suppression for perceived single vision was dependent on the stimulus variables used. Large disparate stimuli appeared single by fusion and sometimes by suppression. Small disparate stimuli appeared single by apparent fusion. In a second study stimuli with large disparities of a 1/2 to 1^{o} of arc were used. A set of control stimuli with the same disparate values were included to control for the possible difficulty of judging a stimulus in depth as being central or non-central. These disparate stimuli were set off centre ie. unequally placed from the midline. If fusion occurred centrality would not have been reported. High proportions of centrality were reported for the control stimuli suggesting that the apparent visual directions were not the arithmetic mean of the two monocular inputs but rather that one eye was weighted more by the visual system than the other even during nonius alignment. Visual directions of stimuli away from the midpoint have also been reported with vertical disparate stimuli of 0-7' of arc (to avoid confusion with the depth effect) and subjects were consistent in their judgements (Sheedy and Fry, 1979). This suggests that ocular dominance effects are involved in directional judgements for stimuli that also do not involve eye movements. However, no systematic study was made of these dominance effects.

In Levelt's (1965) studies on brightness averaging an ocular dominance effect was observed. Equal luminance discs were presented to both eyes and a test pattern of fixed luminance was presented to one eye and a disc of adjustable luminance was presented to the other. Subjects adjusted the luminance of the latter disc so that the binocularly perceived brightness matched the standard equal luminance of the discs. The results supported an averaging luminance model, the average luminance of the test components was judged to be equal to the average luminance of the standard components. If one test component was zero, or very small compared to the standard, averaging did not occur but resulted in Fechnor's paradox. A series of equi-brightness curves were drawn from the data and the slopes were found to depend on the ocular dominance factor, a variation that could also be mimicked by increasing the amount of contrast in that eye. Levelt (1965) suggested the ocular dominance effect reflected a sensory difference but he did not expand it further and nor did he attempt to quantify this difference. This sensitivity difference may be a difference in contrast sensitivity or adaptation.

Sensitivity of the visual system is usually characterised by the contrast sensitivity function. However, such measures cannot be expected to be indicative of performance with suprathreshold stimuli where the stimuli are far more complex possibly involving a range of processes and interactions. The majority of the eye dominance tests involve suprathreshold stimuli, one exception is the test suggested by Ware and Mitchell (1974). They reported interocular transfer of the threshold elevation of contrast between the two eyes and this was greater in one direction of transfer relative to the other. This was suggested to be a good measure of dominance because of the report of greater transfer from the sighting dominant to non-sighting eye relative to the opposite direction. Threshold measures have been taken to reflect the proportions of neurones in a channel although the exact neural interactions are so poorly understood that it is unlikely that the proportion of neurones are the limiting factor even in sensory threshold measurements.

The following studies have looked at sensitivity differences between the eyes at 1) theshold levels and 2) suprathreshold levels.

1. Threshold Measures of Ocular Asymmetries

It is well established that binocular thresholds for luminance detection are lower than monocular thresholds. Pirenne (1943) concluded that this reflected probability summation, the amount of reduction expected from the combination of two independent detectors. However, in a carefully controlled set of experiments (Thorn and Boynton, 1974) binocular threshold reduction was found to exceed that expected from probability summation and this is believed to reflect the neural summation of the two monocular channels. This is called binocular summation. It is possible that those studies that failed to report binocular summation effects (see Blake and Fox,1973, for a review) had subjects with an eye more "sensitive"than the other that may have resulted in suppression of one eye during binocular viewing. Studies that have reported binocular summation have deliberately chosen subjects with approximately equally sensitive eyes (Braccini, Gambardella and Suetta, 1980). Legge (1979) reported that the contrast sensitivity of one observer CF was higher for the right eye compared to the left, and similarly for subject JC in the

Lema and Blake (1977) study. Home (1978) reported sensitivity differences for his subjects between the sighting and non-sighting dominant eyes. The sighting eye was reported to be the more sensitive. Also larger contrast sensitivity differences have been reported between amblyopic and normal eyes (Levi and Harwerth, 1977; Levi, Harwerth and Manny, 1979; Blake, Martens and Di Gianfilippo, 1980)

In a study by Westendorf, Langston, Chambers and Allegretti (1978) the monocular test luminances were varied to achieve a 40% correct detection rate for rectangular flashes. Despite this adjustment all normal subjects did show some variation in the threshold detections for the two eyes eg. DG showed an approximate difference of 14% correct detections between the right and left eyes. No information was supplied on eye dominance.

Selby and Woodhouse (1981) found that the amount of binocular interaction was dependent on the contrast sensitivity ratios of the eyes. For amblyopes, the contrast sensitivities of the two eyes were approximately equal for spatial frequencies of 2 c/° but not for high spatial frequencies. Subjects who had no stereoscopic vision yet demonstrated interocular transfer of threshold elevation of contrast at normal levels for 2 c/° but not at higher frequencies (8 c/°). It was suggested that binocular performance and interactions are improved when the eyes have approximately equivalent contrast threshold sensitivities.

2. Suprathreshold Measures of Ocular Asymmetries

i) Monocular testing

Reaction time is usually used to quantify suprathreshold responses. Simple response times are assumed to correlate with the perceptual strength of the stimulus (Mansfield, 1973) and equal response times reflect equal perceptual strengths, (Minucci and Connors, 1964; Harwerth and Sperling, 1975). A difference in the sensitivities of the two eyes or the processing capacities may be reflected in differential reaction time measures.

Poffenberger (1912) reported that the sighting dominant eye yielded significantly faster response times than the non-dominant eye. However, no difference in response times to detect sinusoidal gratings over a range of contrast levels were reported between the sighting and non-sighting dominant eyes by Blake, Martens and Di Gianfilippo (1980). In this study the contrast sensitivities of the two eyes were made equivalent prior to the experimental measurements. However, one subject did show a 10 to 15% difference in response times. This subject CB was stereoblind, the non-amblyopic eye having the shorter response time.

Minucci and Connors (1964) recorded response times to a 1° flash of light that varied in intensity over a 4 log unit range. The flash was presented to the sighting dominant, sighting non- dominant eye and to both eyes. Monocular presentations resulted in equivalent response times to the binocular viewing condition when the the sighting dominant eye had a stimulus 0.53-0.71 log units brighter and the non-dominant eye had a stimulus 0.85 - 1.4 log units brighter, depending on the binocular brightness level, than the binocular test flash. A measure of dominance based on the difference in these values was correlated with acuity measures and binocular response times. No relationship was found. However, no fixation marker was provided during the experiment and any misalignment due to differences in fixation stability may have contributed to the results. It is not known if these differences would also have existed once asymptotic response levels had been reached.

Money (1972) recorded the percentage of correct localisations for dots and digits flashed for 500 ms under monocular and binocular viewing. No fixation points were provided and subjects could scan the board. Binocular performance was superior to monocular performance and the sighting dominant eye was superior to the non-dominant eye. Reducing the speed to 100 ms reduced the differential between the two eyes suggesting that a difference in the speed of eye movements was responsible rather than a difference in processing capacities.

It is possible that the difference in detection rates between the eyes may have been due to different states of accommodation. Poor accommodation produces optical blur and reduces the contrast sensitivity of the eye (Ogle, 1961) and if no fixation point is provided it is possible that accommodation states may vary from one trial to another.

ii) Binocular Testing

This section is concerned with those studies looking at the proportional contribution of each eye to the binocular percept. It is possible that differences between the eyes are only realised with some form of binocular stimulation. Cogan and Silverman (1980) found that two of their four subjects showed no difference between the eyes for detection of test probes presented monocularly but did show a difference during rivalry and fusion ie. during dichoptic viewing. When the dominant eye (the eye with the higher detection rate) was covered with a neutral density filter, performance was reduced to the same level for each of the conditions of monocular viewing, rivalry and fusion. Covering the non-dominant eye produced a progressive decrease in performance over the three conditions respectively. Thus reducing the contrast or luminance of one eye, possibly reduces the influence of one eye over the other. This may reflect changes in the level of interocular suppression.

Frisby and Mayhew (1979) presented identical textured displays to each eye. The two textures contained monocularly visible regions of different contrast. When fused stereoscopically the texture (see Fig 1c, Frisby and Mayhew, 1979) became homogeneous due to the process of contrast summation (Lema and Blake, 1977). It was noted by the authors that the homogeneity was not immediately apparent if the subject had a dominant eye. This suggests that there is a difference in sensitivity of the eyes at the site of binocular processing. A novel finding of a depth effect was reported with these displays. However, a contrast difference between gratings presented dichoptically is not sufficient to produce a depth effect (Blake and Cormack, 1979b).

Legge and Rubin (1981) designed a series of experiments to measure suprathreshold contrast interactions using a similar paradigm to that of Levelt (1965). A type of eye dominance measure was found for four subjects. The contrast of the test components for a match depended on which eye received the higher contrast test grating. If a low contrast grating was presented to the left eye a high contrast grating to the right eye was required to make a match. If the lower contrast grating was presented to the right eye, an even lower contrast was required by the left eye, and the left eye was designated the dominant eye. Small differences in contrast sensitivity between the eyes mirrored the direction of the contrast dominance measure as derived above but not in magnitude. Individuals showed varying degrees of dominance in the matching contrast curves which varied in magnitude (not direction) for each subject over the different tasks. Subject MA showed extreme ocular dominance which was found not to be related to accommodation differences between the eyes as measured by the laser optometer. This subject also had good stereopsis. It is not known what the basis to this dominance is although it again demonstrates that monocular sensitivies are not good predictors of the type of binocular outcome at suprathreshold level.

However, if the contrast sensitivity difference between the eyes is large binocular performance is impaired. Levi, Harwerth and Manny (1979) reported that binocular performance with amblyopes using reaction time measures was below that of the monocular performance. No compensations for the contrast differences were made prior to binocular performance (cf Blake, Martens and Di Gianfilippo, 1980). A similar result was reported by Selby and Woodhouse (1980) for the threshold elevation of contrast.

There is need for a systematic study of ocular asymmetries in binocular vision. Both direction and degree of dominance need to be investigated. It is possible that the continued use of the word dominance together with the nature of some of the dominance tests and the dichotomous classification have obscured the nature and possible function of eye preferences and ocular asymmetries in binocular vision. The division of motor and sensory factors in the different tests of dominance also needs to be questioned.

1.9 The Aim of This Study

This study is an investigation of the ocular asymmetries in binocular vision using several different dichoptic and binocular viewing paradigms. Part II is concerned with measuring ocular asymmetries between the eyes when different stimuli are presented to each eye which promotes binocular rivalry. A measure of the direction and the degree of the asymmetry is developed from the rivalry results. Part III reports a series of experiments investigating ocular asymmetries when similar stimuli are presented to each eye using a stereoscopic viewing paradigm.

A measure of ocular asymmetry giving direction and degree is developed from the response time measures. Part IV reports a measure of ocular asymmetry derived from an interocular transfer paradigm and the models of interocular transfer are reviewed in relation to the different asymmetry measures reported in previous experiments.

PART II

BINOCULAR RIVALRY MEASURES OF OCULAR ASYMMETRY

CHAPTER 2

2.1. Introduction

Double images are rarely experienced under normal viewing conditions unless there is a misalignment of the visual axis as in the clinical case of strabismus. When fixation is changed from one object to another the convergence angle of the eyes is changed so that they remain aligned and reduce the disparity of the two images of the object resulting in single vision. Single vision occurs for disparate images as long as the disparity is within a certain range (Panum, 1858) This limited range for single vision is known as Panum's fusional range. It is usually taken to be about 9-15' of arc horizontally and 5-8' of arc vertically (Mitchell, 1966). However, the dimensions of this fusional area depends on the method of measurement (Duwaer and Van Den Brink, 1981).

If the disparity of an object is small it is perceived as single although each monocular image of that object specifies a different visual direction. There are two theories that have been proposed to explain binocular single vision; the suppression theory (Porta, 1593; Du Tour, 1760; Verhoeff, 1935; Asher, 1953; Hochberg, 1964; Kaufman, 1974) and the fusional theory (Boring, 1933; Charnwood, 1952; Sperling, 1970; Julesz, 1971). The suppression theory holds that one image or part of an image is suppressed in binocular vision by the other, and the dominant image specifies the visual direction of the objects in space. (A weaker version of the theory held by Hochberg (1964) holds that the binocular percept is composed of a mosaic from the two images by a process of local suppression over the two retinae). Binocular rivalry is taken to be the phenomenal expression of the process of suppression that occurs in normal binocular vision.

The fusion theory holds that the single binocular percept results from a "compromise" or "fusion" between the two monocular images. Visual directions of objects are specified by a value intermediate of the two monocular values.

If binocular rivalry or suppression is the basis to binocular single vision it is unlikely to be experienced because of the similarities of the two images. The study of single vision has been investigated in an either/or manner, either suppression occurs or fusion occurs, and several psychophysical techniques have been used to test for fusion or suppression effects. The classical views of visual suppression and of visual perception have influenced the procedures adopted to test for fusion or suppression.

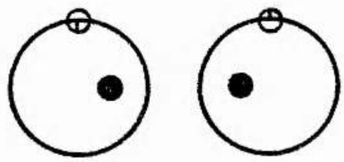
Suppression was mentioned in the 16th and 17th centuries by Porta (1593) and Gassendi (1698) and later by Du Tour (1760) as the basis to single vision. One eye perceived the world despite both eyes being open. This view was expanded by later theorists (Washburn, 1933; Verhoeff, 1935; Hamburger, 1949; Asher, 1953). Verhoeff believed that one eye became dominant because greater attentional value was attached to one image while the other image was suppressed. He called this process replacement rather than suppression. Asher (1953) claimed that it was one member of a pair of corresponding points that was suppressed although he reported that depth was still apparent with non-corresponding disparate stimuli despite this suppression. Several investigators believed suppression ie. binocular rivalry was the basis to stereopsis (Washburn, 1933; Hochberg, 1964). However, it has been well documented that depth is still perceived with disparate images that are also rivalrous (Helmholtz, 1925; Kaufman, 1964; Kaufman and Pitblado, 1969). Depth is also experienced with disparate images that are perceived as double images (Ogle, 1953). Therefore, fusion and suppression are not necessarily sufficient conditions for stereopsis (Ono, Angus and Gregor, 1977).

Alternating suppression as experienced with discrepant images in binocular rivalry was believed to reflect an on going competition between the eyes. Washburn and Manning (1934) reported phenomenal rivalry while viewing a 3 dimensional object, a black cube with one vertical white side. Miles (1929) believed that single vision was achieved by suppression of one image and not by a process of alternating suppression, thus one eye became the dominant eye in binocular vision.

Evidence for suppression in single binocular vision has been sought using a variety of experimental paradigms. If the traditional definition of suppression and fusion is used (Asher, 1953) the visual direction of an object will be dependent on which process is operative. If fusion occurs, the image will appear "displaced" to an intermediate position of the two monocular visual directions. If suppression occurs the visual direction of an object will correspond to that of one monocular image.

An alternative approach has been to use the test probe technique. The test probe, that is a small flash of light monitors the threshold sensitivity of a stimulus. It has been reported that the sensitivity threshold of a test probe (ie its detectability) is reduced by 0.5 log units during the suppressive phase of binocular rivalry (Wales and Fox, 1970; Fox and Check, 1972; Blake and Camisa, 1979). Test probes are presented during binocular rivalry, apparent fusion and monocular viewing of a stimulus. The threshold sensitivity of the test probe is monitored during these viewing conditions and if the sensitivity is reduced by 0.5 log units, suppression is assumed to be occurring.

Ono et al (1977) conducted a study using the first experimental procedure outlined above. They found that the prevalence of suppression or fusion was dependent on the stimulus variables such as the size of the stimuli and the amount of disparity between the images. Using the stereogram shown below, subjects were required to report on the "centrality" of the dots. If the fused dots appeared central the direction of the image was intermediate of the values of the monocular images and fusion is inferred. Reports of "non-centrality" indicated that suppression of one image had occurred, and the visual direction of the dot was specified by one monocular image.



Stereogram used in the study of Ono, Angus and Gregor (1977)

The test probe technique has been less successful and non-conclusive. The reduced sensitivity of the test probe during rivalry suppression has been reported as small, ranging from 0.1 to 0.56 log units (Hollins and Bailey, 1981). Reports of suppression during apparent fusion have also been mixed. Some researchers have failed to find evidence for suppression during apparent fusion (Fox and Check, 1966; Blake and

Camisa, 1979) and others have found evidence for suppression using the same test probe techniques (Fox and McIntyre, 1967; Makous and Sanders, 1978; Westendorf and Fox, 1978). Fluctuations in sensitivity may have contributed to some of the findings especially given the small values of reduced sensitivity reported above. Spurious alternations in sensitivity have not been controlled for in many of these studies (Cogan and Silverman, 1980; Cogan, 1982).

2.2. Classical Views on Rivalry Dominance

Theoretically, binocular rivalry has been viewed as one eye competing with the other for the visible percept. Therefore it is not surprising that measurement of binocular rivalrous images has involved the use of only two response categories, one to register the phenomonal dominance of the image for the right eye and one for the appearance or dominance of the image to the left eye. A dichotomous classification has been used, ie. the right eye or the left eye is designated as dominant. This is the same procedure that is used for the results from sighting dominance tests. Some investigators adopted an arbitrary criterion by which to judge if one eye was dominant over the other. If the total amount of time one image was recorded as being visible exceeded the duration the other image was visible by 20%, then that eye was judged to be the rivalrous dominant eye (Washburn, Faison and Scott, 1934). This criterion for dominance again imposed a dichotomous classification. However, Washburn et al (1934) found that with the rivalrous stimuli used in their experiment, (red and blue coloured fields) subjects reported experiencing composites or intermediate colours ie. "purple". The duration "purple" was reported to be visible was halved and added to each of the two other categories.

2.3. Measurement of Binocular Rivalry between Images

A two switch key procedure has usually been adopted for recording the alternations of rivalrous images. However, several problems arise if the stimuli are large and exceed 1^{o} to 1.5^{o}'s in diameter. Rivalry becomes piecemeal and there are few whole alternations (Blake and Fox, 1974a). A response category or categories are rarely provided by which to record these visible occurrences. If the rivalry between the images is not clear cut, it is possible that responding will become more variable introducing possible response bias effects. Therefore, there has been a tendency for researchers to use small rivalrous images.

However, it has been reported that even with small rivalrous stimuli 40-60% of the inspection time is experienced as combinations or composites of the two monocular images (Wade, 1975b; Hollins and Bailey, 1981). Simultaneous disappearances of both images have also been reported for prolonged viewing (10 minutes) of rivalrous stimuli (Rainwater and Cogan, 1975).

Recordings of rivalrous images are assumed to correspond to the phenomenal alternations of dominance and suppression and it is important that the appropriate response categories are available by which to record this pattern. It is from this re-description that the mechanism or process of rivalry is inferred.

Given that composites or combinations of the two images have been reported to occupy a high percentage of the observation period it questions the theoretical view that binocular rivalry is a competitive process of one image with the other. Meenes (1930) reported that suppression occurred in a piecemeal fashion over the retinae and the binocular image is a mosaic composed of parts of each monocular image. This view has been supported by observations with rivalrous images (Creed, 1935; Hamburger, 1949) and from experimental studies (Wade, 1974). Local suppression over the images rather than suppression of one whole eye questions the classical view of the role of suppression in normal binocular vision. It is possible that the binocular percept is composed of the two images and form the "cyclopean field" along the lines suggested by Hochberg (1964).

2.4. The Use of Binocular Rivalry as a Measure of Ocular Dominance

Binocular rivalry has not been given much attention in the literature as a measure for eye dominance despite its association with the study of single binocular vision. This may partly be due to the preoccupation with sighting dominance and laterality in the 1920's and 1930's (Schoen and Scofield, 1935). Binocular rivalry was also considered a difficult task to administer (Walls, 1951) and to be statistically unreliable (Ogle, 1962).

When it has been used as a measure of dominance, a dichotomous classification has been used. It has been suggested that visual suppressive effects may vary in strength along a continuum, with constant suppression of one eye at one end as found with constant strabismus, to temporary suppression found in normal binocular viewing that may occur while performing a sighting task (Coren and Duckman, 1975; Blake and Lehmkuhle, 1976). Therefore it may be expected that individuals will vary in the degree of eye dominance as well as the direction. Binocular rivalry measures may well be suited to show this variation in dominance strength between subjects. Wade (1976a) graded a group of subjects in their strength of rivalry dominance. The dominance score was derived from the ratio of the total duration the image to the left eye was visible to the total duration the image to the right eye was visible. This score, giving both direction and degree was compared to the amount and direction of maximum transfer of the movement aftereffect.

2.5. Ocular Dominance: Wade's hypothesis (1978b)

Low correlations between sighting dominance and rivalry dominance have been reported in the literature (Coren and Kaplan, 1973). An hypothesis has been put forward by Wade (1978b) to explain why sighting dominance and rivalry dominance are not related.

Rivalrous lines were presented to the two eyes oriented at 0° (vertical) and 90°, or 0° and 45° (Wade, 1975a). The orientations were counterbalanced between the eyes. The image in one eye was reported to be visible for longer than the image in the other over the 90 second inspection periods. An eye dominance measure was calculated expressing the total durations the left eye and the right eye were reported as visible as a ratio. When the same stimuli were presented as afterimages, the eye dominance effect was reduced, that is, the total durations the left and right eyes were seen were approximately the same.

Wade (1975a) suggested that the eye dominance results found with real image rivalry were due to small eye movements that resulted in movement of the contours of the stimuli over the two retinae. Greater eye movement instability of one eye was claimed to result in the image to that eye being visible for longer than the other and were being designated the dominant eye. Small eye movements displace the contours of a stimulus on to new areas over the retinae stimulating new receptive fields and are assumed to keep that pattern in view for longer relative to a pattern that is fixated with more stability. Clearly some eye movements are required to maintain visual stimulation although it is unlikely that that the stimulus on the more stable eye will fade from view. However, if one eye moves more than the other while viewing binocular contoured rivalrous stimuli, the image to this eye will slide over the other one leaving a "wake" of spreading suppression. Thus the image to the less stable eye is believed to remain visible for longer and to suppress the other (Kaufman, 1963).

When the stimuli are presented as afterimages, any contour displacement due to eye movements is eliminated, and any dominance effects are claimed to be due to interocular suppression. This is assumed to be equal between the eyes (Wade, 1975a). In support of the eye movement hypothesis, Wade (1975a) reported that there was an interaction of the dominance effect with the orientation of the lines. A vertical line was seen for longer than an horizontal line (non-significant effect) and it was more marked if the vertical line was presented to the dominant eye ie. the least stable eye.

Wade (1975a) suggested that this effect may be explained by horizontal non-conjugate eye movements that occur during rivalry (Kaufman, 1963). Horizontal eye movements would displace the whole vertical contour onto a new retinal area, whereas only the ends of the horizontal line would be displaced. The dominant eye is therefore assumed to make more eye movements than the other one and mainly in the horizontal dimension.

The eye movement hypothesis was extended further to account for the discrepancies in the literature between sighting dominance and rivalry dominance (Wade, 1978b). He suggested that the two tasks of sighting and rivalry were weighted differentially on eye stability and interocular suppression. In a sighting task the most stable eye would be favoured as the dominant eye because of the ability to maintain fixation. In a rivalry task it would be the least stable eye that would be the dominant eye, as outlined above. If these eye movement interactions with the stimuli are removed that is, with afterimage presentation, interocular suppression alone is responsible for any eye asymmetry that may result. Therefore, the rivalrous dominant eye will not be expected to be the sighting eye in the sighting dominance tests. No data on sighting performance was included in the above studies on rivalry.

It may be argued that a clearer image is required for the sighting eye, that is for accurate alignment of the two objects and it may be expected that image movement caused by small eye movements may produce this clarity. Marshall and Talbot (1942) argued that visual acuity is improved by constant motion of the image over the receptors. However, there is no evidence that this is the case. Therefore, the eye dominance effects with real image rivalry that are claimed to be due to eye movement instability are probably associated with spreading suppression of the moving contours of one stimulus over the other (Kaufman, 1963). Also, the dominance effects reported by Wade (1975a) were present when horizontal contours were presented to that eye which may suggest that the instability of this eye is not restricted to the horizontal domain. Alternatively, some other factor may be responsible. Sabrin and Kertesz (1980) recorded microsaccades during rivalry with ring-disc stimuli. Greater microsaccadic activity was recorded during the dominant phase of the stimuli and also for the right eye (which may have been the dominant eye although this was not reported) even during phenomenal suppression of this eye's image. It is not known if more eye movements occurred preceding a dominance phase or that these were asymmetrical between the eyes. As a sufficient test of this hypothesis eye movements would have to be recorded during real image rivalry and afterimage rivalry viewing and during the sighting test.

The hypothesis put forward by Wade (1978b) may explain the binocular rivalry results (1975a) but it would also be expected to explain the visual function of the eyes in binocular vision. Binocular rivalry studies usually use zero disparate stimuli but in a sighting task eg. alignment there are large disparities involved, that is the near target appears double if fixation is on the far target. With fixation of one target, one of the double images is chosen for alignment. It may be expected that the image more often dominant or prominent would be chosen and this may correspond to the rivalrous dominant eye. However, according to the above hypothesis alignment is performed by the stable eye, the dominant eye, the visual field of which may be under partial suppression by the other rivalrous dominant eye.

Eye movement differences may explain the results from the dominance tests and the poor association between them but it is questionable if a comparison of the dominance tests is warranted given the dichotomous classification used. Both sighting and rivalry dominance have been influenced by the classical views on single vision and the former by the concern with motor laterality. It is quite possible that a dichotomous classification of the results is simply a reflection of the nature of the tasks which adds little to the understanding of binocular vision.

2.6. Hypotheses to be Tested

Four experiments are reported in the following chapters three on binocular rivalry and one on sighting behaviour to investigate the following.

1). To devise a measure of ocular dominance using the binocular rivalry procedure, that would indicate direction and degree of dominance.

2). To measure the consistency of this measure of rivalry dominance over experimental sessions held on separate days.

3). To test the eye movement hypothesis of Wade's (1978b);

i) the dominance measures would be found with binocular rivalry with real images (Chapter 3).

ii) the dominance measure would be reduced or eliminated with binocular rivalry with afterimages (chapter 4) thus indicating that eye movements and the spread of suppression are responsible for the dominance effects.

iii) the rivalrous dominant eye derived from (i) would not be the sighting eye (chapter 7).

4). To test if the rivalry pattern using the classical two response procedures (that is one response for each of the whole images and no response required at all for composites) would be changed if a direct response for recording composites was introduced (as well as recording durations of total disappearances), and if the measures of rivalry dominance would change in terms of the strength of dominance (chapter 6).

CHAPTER 3

Binocular Rivalry with Real Images as a Measure of Ocular Asymmetry

3.1. Introduction

The aim of the experiment reported in this chapter was to record binocular rivalry between real image stimuli and to develop a measure of ocular asymmetry based on the total duration each image was reported as visible. Wade (1975a) reported asymmetries for four subjects using single lines viewed as rivalrous real images.

Small orthogonal gratings (1.25° in diameter) obliquely oriented 45° from the vertical were used to promote whole image rivalry (Blake and Fox, 1974a) and reduce partial suppression effects found at the intersection of the lines. Vertical and horizontal gratings were not used in order to eliminate any interaction between contour orientation and ocular dominance factors.

Eight subjects participated in all four experiments. A two switch key procedure was adopted in this and the following studies. The overall durations each grating was reported as visible, the duration of each visible phase and the frequency of the visible occurrences were recorded during the 90 second inspection periods or trials. The 90 second inspection period was divided into three 30 second phases by the computer in order to monitor variations in the rivalry pattern throughout the trial for direct comparisons to be made with Wade's data (1975a).

3.2. Method

3.2.1. Subjects

Eight subjects from the University of St Andrews participated in the experiment. They had had no previous experience of reporting rivalry. All had normal or corrected 6/6 vision.

3.2.2. Apparatus

Subjects viewed the stimuli in a modified stereoscope arrangement shown in Fig 3.1. Two 10 diopter glass prisms were mounted in the eye holes, base out, and surrounded by a pair of cut away goggles to cut out any external light. The stimuli were mounted on cards and slotted into the back of the stereoscope 57 cms away from the eye holes. The stimuli were back illuminated by a lamp with a diffusing screen in front.

Two switch keys were positioned on either side of the stereoscope for the subjects right and left hands. These were connected on-line with the computer (Nova 1220) which recorded the duration each key was depressed and the frequency of depressions over the inspection periods

3.2.3. The Stimuli

The rivalrous stimuli consisted of two square wave gratings, 3.2 cycles per degree, one oriented 45° clockwise from the vertical, the other 45° counter clockwise from the vertical. The stimuli were made from photographic negatives in the form of circles that subtended 1.25° of visual angle. The immediate surround to the gratings was black. The negatives were mounted on cards that could be moved horizontally to adjust for binocular alignment. The contrast of the gratings (1) were 0.5, the space average luminance was 0.5 cdm -2 and the surround was 0.4 cdm -2.

3.2.4. Procedure

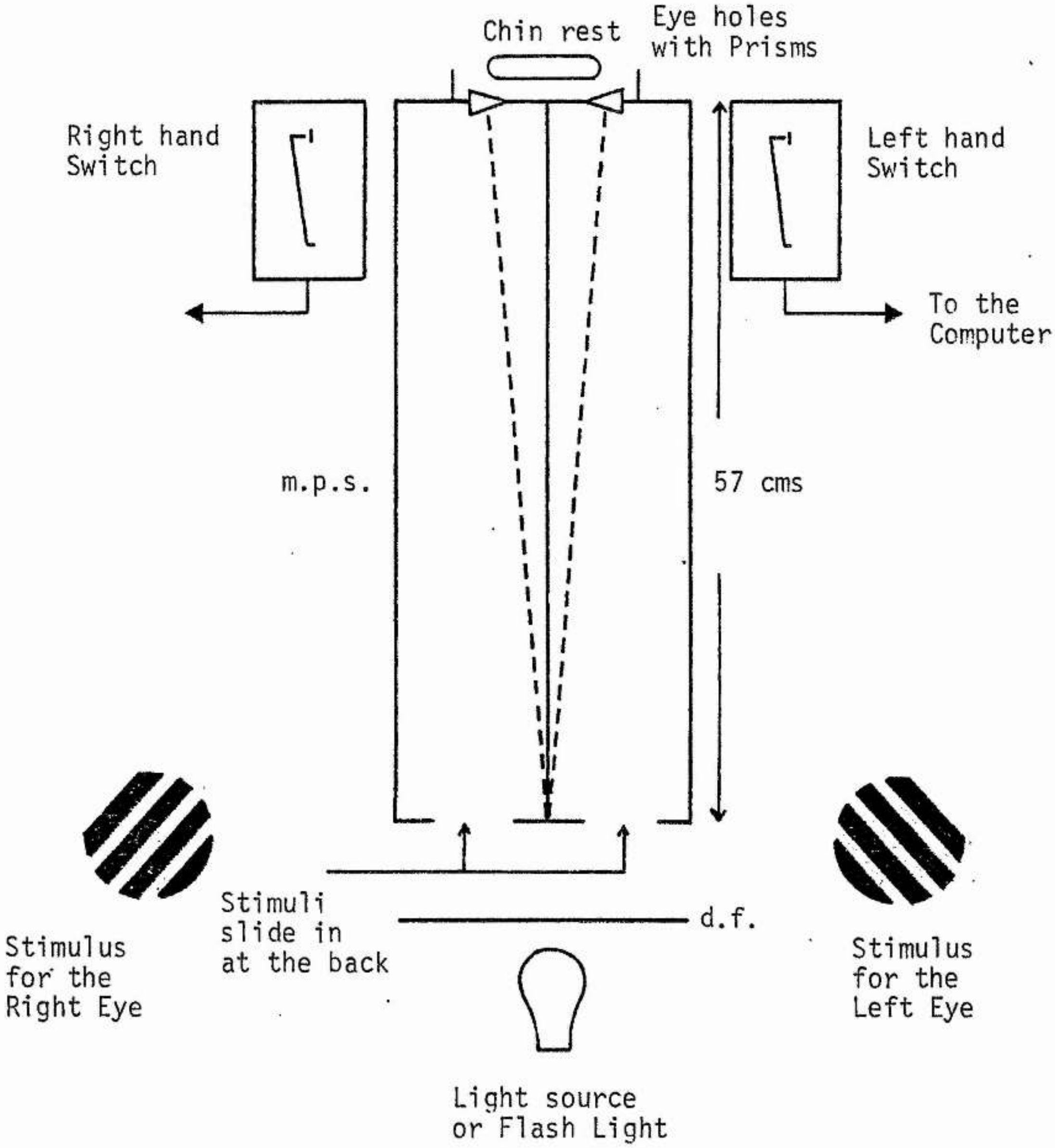
The stimuli were adjusted for binocular alignment for each subject before any recording began. The subjects task was to press the right hand switch for the duration of time the clockwise oriented grating was visible and the left hand switch for the duration the counterclockwise oriented grating was visible.

(1) Contrast was derived from the following formula;

$$C = \frac{(L\ max) - (L\ min)}{(L\ max) + (L\ min)}$$

L max = maximum luminance in cd/m2
L min = minimum luminance in cd/m2

Fig 3.1 Plan View of Apparatus Used for the Binocular Rivalry Experiments.



d.f. - Diffusing Screen
m.p.s. - Modified Prism Stereoscope

Subjects were told to press the switches only if the images were seen in their entirety, neither switch was to be pressed if any combination of the two images was visible.

Five experimental sessions were given, held on separate days. Each session consisted of six 90 second observation trials with an inter trial interval of two minutes during which time the stimuli were covered from view. A warning tone preceded each observation period. For the first three trials of each session the right eye grating was oriented 45° clockwise and the left eye grating 45° counterclockwise. The left and right switches were depressed for the stimuli to the right and left eyes respectively. For the following three trials the gratings were interchanged the right switch was depressed for the right eye's grating oriented 45° counterclockwise and the left switch for the left eye's clockwise oriented grating. This procedure was designed to reduce any bias in reporting a grating at a certain orientation.

3.3. Results

The mean amount of time each grating was visible within the 90 second inspection period is shown for each subject in Table 3.1a, averaged over all trials and experimental sessions. Exclusive visibility of one or other image occurs for 87% of the total viewing time and this varies over the three inspection periods, increasing from 81.5% in the first 30 seconds to 90.1% in the remaining 60 seconds. The remaining 13% may have been either composites or total disappearances of the gratings. Each subject shows a difference in the durations the left and right eye's images are reported to be visible and this is maintained throughout the inspection period as can be seen from the ratios of the total time the left grating was visible to that of the right as shown in Table 3.1b.

An analysis of variance was carried out on the overall durations each image was visible, the duration of each visible phase and the frequency of the visible occurrence. The five factors were: the experimental sessions (5 days), trials (six 90 second trials), the inspection periods (three 30 second inspection periods) and the two rivalrous stimuli (one for the left eye and one for the right eye). (The summary tables for the analyses of variance and post-hoc comparisons are in Appendix B).

Table 3.1a Mean Overall Durations (seconds) Each Image is Visible for Each Subject for the Three, 30 second Inspection Periods (2). (1 Standard Deviation is shown in brackets).

	Inspection Periods					
	0 - 30 seconds		30 - 60 seconds		60 - 90 seconds	
Image Seen:	LE	RE	LE	RE	LE	RE
Subjects :						
GR	13.18 (2.70)	9.73 (1.71)	14.44 (3.57)	10.79 (2.87)	13.54 (4.01)	10.09 (2.30)
SW	14.72 (2.14)	11.64 (1.57)	15.89 (2.09)	12.15 (2.56)	15.88 (2.15)	12.25 (1.76)
SK	13.98 (2.12)	11.98 (1.92)	14.97 (1.58)	13.44 (1.56)	14.50 (2.13)	13.86 (1.46)
SM	17.38 (3.57)	9.63 (4.51)	17.92 (7.15)	11.72 (5.59)	19.18 (5.33)	10.61 (4.86)
GM	11.53 (2.43)	14.81 (2.53)	13.13 (2.78)	17.21 (3.39)	13.59 (2.69)	16.80 (3.10)
ID	9.98 (5.08)	7.14 (3.80)	12.87 (7.50)	7.74 (5.20)	10.67 (8.67)	6.82 (5.21)
AH	12.37 (1.81)	11.81 (1.53)	14.75 (2.94)	12.98 (2.18)	13.71 (2.02)	12.36 (1.66)
CB	13.10 (1.61)	12.74 (2.32)	14.86 (2.17)	14.99 (2.02)	14.12 (1.57)	14.66 (2.10)
MEAN	13.27	11.19	14.85	12.63	14.40	12.18

LE - Left Eye RE - Right Eye

Table 3.1b Ratios of the Mean Overall Durations (above) of the Left Eyes Image to the Right Eyes Image for the three 30 second Inspection Periods (2)

	Inspection Periods		
Subjects:	0 - 30 seconds	30 - 60 seconds	60 - 90 seconds
GR	1.35 : 1	1.34 : 1	1.34 : 1
SW	1.26 : 1	1.31 : 1	1.30 : 1
SK	1.17 : 1	1.11 : 1	1.05 : 1
SM	1.80 : 1	1.52 : 1	1.80 : 1
GM	0.78 : 1	0.76 : 1	0.81 : 1
ID	1.39 : 1	1.66 : 1	1.56 : 1
AH	1.05 : 1	1.14 : 1	1.11 : 1
CB	1.03 : 1	0.99 : 1	0.96 : 1

(2)Mean overall durations are the sum of each duration of depression of each key switch within the 30 second inspection period averaged over the 6 trials of the 5 experimental sessions.

There was a significant difference in the overall durations the images were visible over the three 30 second inspection periods ($F = 32.7024$, df 2,14, $p<0.00001$). A post-hoc comparison between the means using the Scheffé test (Hays, 1963) showed a significant increase from the initial 30 second period to the remaining 60 second period with a mean difference of 1.22 secs ($p<0.01$). This pattern was also mirrored in the mean duration of each depression, the mean difference being 0.29 secs. ($p<0.05$) and these were for the two images combined, 1.82 and 2.11 seconds for the first 30 seconds and last 60 seconds inspection respectively. There was no significant difference in the frequencies the two images were visible over this period ($F=1.2818$, df 2,14, not significant), the mean value was 7.50 alternations in each 30 second inspection period.

There was no significant difference between the overall durations the left eye's image and right eye's imageswere visible ($F=3.575$, df 1,7, $p>0.10$), the durations of each depression or visible phase ($F=2.47$, df 1,7,$p>0.10$) and the frequencies of the visible phases ($F=0.023$, df 1,7, not significant). There was no significant interaction between the overall durations of the visible phases for the left and right eye's images with the five days of experimentation ($F=0.64$, df 4,28, not significant) or with the six trials ($F=1.29$, df 5,35, not significant). This pattern of non significance was also mirrored for the durations of the depressions and frequencies of the visible phases.

3.4. Measures of Ocular Asymmetry

Table 3.2 shows the overall mean durations the images for the left and right eyes were reported as visible over the 90 seconds of observation (ie. the three 30 second periods were summed). There was no significant difference in these durations for the two eyes which is not surprising given a group of subjects of mixed strength and direction of dominance.

Table 3.2 Mean overall durations each image is reported as visible (seconds) and standard deviations (SD) over the 90 seconds of observation (3) for each subject.

Subjects:	LEFT EYE	SD	RIGHT EYE	SD
GR	41.16	7.86	35.88	8.79
SW	46.50	5.31	36.03	4.59
SK	43.44	5.10	39.27	3.96
SM	53.22	14.79	31.98	14.61
GM	38.25	3.24	48.84	3.30
ID	33.42	16.29	21.69	12.03
AH	40.83	5.73	37.14	3.48
CB	42.09	3.03	42.39	4.30

(3)The mean overall durations over the 90 seconds are the average of the result from the 6 trials in each of the experimental sessions.

A measure of dominance or ocular asymmetry was derived using the formula below:

$$\text{Dominance score} = \frac{LE - RE}{LE + RE}$$

LE = overall duration the left image was visible over the 90 seconds of observation.

RE = overall duration the right image was visible over the 90 seconds of observation.

The mean ocular asymmetry score for each subject over trials is shown in Table 3.3. A value of 0 would indicate no asymmetry or dominance and a value of +1 would indicate a totally dominant left eye and a value of -1 a totally dominant right eye.(4)

Table 3.3 Ocular Asymmetry Scores

Subjects:	Mean Asymmetry Score(5)	+-1SD
GR	0.14	0.12
SW	0.128	0.09
SK	0.05	0.08
SM	0.26	0.34
GM	-0.12	0.07
ID	0.19	0.03
AH	0.044	0.07
CB	-0.0022	0.05

(4)Eye dominance with binocular rivalry measures has usually been expressed as a ratio of the durations the left to the right eye's images were seen (Wade, 1975a) unless a dichotomous classification was used as adopted by Washburn et al (1934). Using this formula in the present study subjects are graded along a symmetrical continuum with a fixed range ie. + 1 to - 1. Using a ratio scale it would be difficult to distinguish relative differences in strengths of dominance given that the durations whole images are visible may vary from individual to individual, and the scale would not be fixed in length.

(5)The mean asymmetry scores correspond almost exactly to the asymmetry scores derived from the overall mean durations the left and right eye's images were visible as shown in Table 3.2. However, for some subjects with weak dominance the direction of dominance varied on some of the trials and this variability would be obscured if the mean overall durations were used.

An analysis of variance was carried out on the asymmetry scores over the trials and experimental sessions. There was no significant variation of these scores over the trials (F=1.228, df 5,35, not significant) or over the five experimental sessions (F=0.58, df 4,28, not significant). All interactions failed to reach significance.

3.5. Discussion

Whole images were recorded as visible for 87% of the observation period over all subjects and it is assumed that the remaining 13% was occupied by either composites or total disappearances. Other studies that have used real image rivalry have reported much higher percentages of composites (Wade, 1974; Hollins and Bailey, 1981). Wade (1975b) reported a figure of 42% for composites using 3° diameter gratings of the same colour. This difference may be a reflection of the different procedures used. However, Wade (1974) reported that 36% of the viewing time was recorded as composites for grating stimuli using a two switch procedure, ie. one switch was pressed for each image and neither switch was pressed when combinations of the two images were visible. As can be seen from Table 3.2 there is considerable variation between subjects on the amount of time whole images were visible, for example subject ID reports that for 61% of the observation period whole images were visible (ie. left or right) whereas subject CB reports that 94% of the observation period was exclusively of whole images.

There is an increase in the overall mean durations whole images are reported as visible during the 90 seconds of observation. This increase is reflected in an increase in the durations of each depression although not in the frequencies each image was visible. Two explanations can be given. First, composites may be seen more frequently at the beginning of the observation period and decrease over time accompanied by an increase in the appearance of whole images. This may be due to a decrease in apparent contrast of the gratings with prolonged viewing (Blakemore, Muncey and Ridley, 1971, 1973). Harwerth, Smith and Levi (1980) reported that at high contrasts (0.63) subjects experienced piecemeal rivalry for briefly flashed orthogonal gratings which would be classed as composites in this study. However, it has been reported that decreasing the contrast or strength of the rivalrous images also affects the rate of alternation or visible occurances (Breese, 1899). The frequency did not change over the observation period in this study. Also Hollins (1980) reported an opposite finding to Harwerth et al (1980), at high contrasts (0.65) whole images were visible. Composites were not directly recorded in the experiment reported in this chapter and it is not possible to determine changes in duration of this category over this time period.

The second explanation may be that of response bias. Durations of each depression or periods of dominance were quite short. A mean duration of 2 seconds was reported in this study compared to 3.8 seconds reported by Wade (1975a). Given that only two response categories were available subjects may have developed an alternating switching mode that would have progressively shortened the amount of time that neither key was depressed ie. the response required to register the occurrence of composites. This may only be tested if composites are recorded directly using a compatible mode of responding.

Measures of ocular asymmetry were reported for each subject. Six subjects show a left ocular asymmetry and two subjects a right ocular asymmetry. There was no systematic change in these dominance scores over the trials or over the five days of experimentation. This suggests that rivalry is a consistent measure of asymmetry (Ogle, 1962). However, there is some variation in the degree of this asymmetry for each subject as can be seen from Table 3.3. Subjects SM and GR show a lot of variability. The mean duration each image was visible was 2.39 seconds for the rivalrous dominant eye compared to 1.66 seconds for the rivalrous non-dominant eye. (This excludes subject CB who has durations for the visible phases of 1.94 and 1.97 seconds for the dominant and non-dominant eyes respectively and has a small asymmetry score).

In the present experiment a measure of ocular asymmetry or eye dominance has been derived with real image binocular rivalry that gives direction and degree of asymmetry. In earlier studies one eye was classed as dominant if one image was reported to be visible over the observation period for a total time 20% greater than the other (Washburn, Faison and Scott, 1934). If that same criterion is applied to the results in Table 3.2 only four subjects would be judged to have a dominant eye, ie. subjects SW, SM, GM and ID.(6)

The measure of ocular asymmetry reported in this study was fairly consistent over the experimental periods of five days. Few composites were reported in this study suggesting that binocular rivalry measures of ocular asymmetry are an expression of the competition between the eyes although the above finding may be a reflecton of the procedure used to measure rivalry. The ocular asymmetry scores support the findings reported by Wade (1975a): measures of ocular asymmetry can be derived from real image rivalry although in this study different stimuli were used. This measure of ocular asymmetry may reflect asymmetry of interocular suppression or alternatively, may be due to a difference in eye movement stability of the two eyes interacting with the contoured stimuli as proposed by Wade (1975a, 1978b). The experiment reported in chapter 4 was designed to test this hypothesis of Wade's using afterimage binocular rivalry.

(6)Measures of ocular asymmetry may have been expressed as a difference in the overall durations each image is visible. However, this would lead to an open ended continuum for the dominance scores that would not be an interval scale.

CHAPTER 4

Binocular Rivalry with Afterimages as a Measure of Ocular Asymmetry

4.1. Introduction

Measures of ocular asymmetry have been derived from binocular rivalry reports using gratings as real image rivalrous stimuli (chapter 3). The experiment reported in this chapter was designed to test the hypothesis of Wade's (1975a, 1978b) that asymmetries in the perception of the images of the two eyes in rivalry are reduced if viewed as afterimages. The real image rivalry asymmetries reported by Wade were claimed to result from instability of the eye movements of one eye ie. the dominant eye. Any contour movement over the retinae as a consequence of eye movements (and believed to keep that image in view for longer) is eliminated when the rivalrous stimuli are presented as afterimages.

The experiment reported in this chapter is essentially the same as the binocular rivalry experiment reported in Chapter 3 except that afterimages were used instead of real images.

4.2. Method

4.2.1. Subjects

The eight subjects from the previous experiment participated in this one. All had normal or corrected 6/6 vision and had had extensive practice at reporting binocular rivalry.

4.2.2. Apparatus

The apparatus was essentially the same as in the experiment reported in chapter 3, see Fig 3.1, see page 61. The light source was replaced by a Bowens Monolite 400 Flashgun with an output of 400J in 400 ms (according to the manufacturer's specifications) to generate the afterimages. The light was attenuated by the diffusing screen and a dim light back illuminated the stimuli prior to each flash to allow for proper binocular alignment. The flash was activated on-line by the computer.

4.2.3. The Stimuli

The stimuli were exactly the same as those used in the experiment reported in chapter 3. The space average luminance of the gratings with the back illumination was 0.30 cdm-2.

4.2.4. Procedure

Each subject was given a brief description of the type of images seen with prolonged afterimage viewing. They were told that they may appear coloured, change colour and drift in view.

Subjects were given ten minutes of dark adaptation prior to the start of the experiment. The procedure was similar to that reported in the previous experiment. However, a warning tone preceded the presentation of the flash during which time the rivalrous stimuli were briefly back illuminated. The subject remained in complete darkness for the 90 second observation period. Subjects were told that the afterimages could be viewed with the eyes open or closed which ever they preferred. Whichever procedure they adopted was maintained throughout all the experimental trials. (All subjects reported viewing the afterimages with the eyes closed). Each subject was dark adapted for a further five minutes between each trial. The presentation of the rivalrous gratings and the associated switch depressions were counterbalanced as in the previous experiment.

All subjects were given two practice sessions, six trials in each at viewing rivalrous stimuli presented as afterimages. It was felt necessary to give an initial practice session with afterimage viewing because subjects sometimes blinked at the moment of discharge of the flashgun and several of the subjects failed to report strong alternations between the stimuli for the first few trials.

Subject were given three experimental sessions held on three separate days with six trials in each session. Each trial was 90 seconds long.

4.3. Results

The overall durations each stimulus was reported as visible, the durations of each depression and the frequencies of visible periods were recorded as in the last experiment. However, subjects reported a fading of the afterimages towards the end of the 90 second period of inspection and they were frequently reported to have disappeared before the inspection period ended. Binocular rivalry measures were therefore based on the first 60 seconds of observation which were also used in the analyses.

Table 4.1 shows the mean overall durations the right and left afterimages were reported as visible for the two 30 second inspection periods averaged across trials and experimental sessions. It can be seen that 80% of the viewing time is occupied by one or other whole image, the remaining 20% is assumed to be either composites or total disappearances. The total time whole images are reported to be visible increase from the first 30 seconds of viewing (73%) to the second 30 seconds of viewing (86%). Subjects also show individual differences in the total durations the two images are reported to be visible.

An analysis of variance was carried out on the overall durations each image was visible, the durations of each switch depression and the frequencies of the visible phases. The factors in the analysis of variance were: experimental sessions (three days of experimentation), trials (six 60 second trials), inspection periods (two 30 second inspection periods), and the stimuli to each eye (two). (The summary tables and post-hoc comparisons are given in Appendix C).

There was a significant increase in exclusive visibility from the first 30 seconds to the second 30 seconds of viewing. ($F=10.32$, df 1,7, $p<0.02$). This increase was also mirrored in an increase in the durations of the depressions over these two periods ($F=12.29$, df 1,7, $p<0.01$) from a mean of 3.03 seconds for the first 30 seconds to a mean of 4.7 seconds for the second 30 seconds. However, this was also accompanied by a decrease in the frequencies that both images were visible from a mean value of 4 to a mean of 3.3 for the first and second inspection periods respectively ($F=39.35$, df 1,7, $p<0.0004$).

The difference between the mean overall durations the images to the left and right eyes were visible did not reach significance ($F=1.25$, df 1,7, $p=0.30$), see Table 4.2.

Table 4.1 Mean Overall Durations (seconds) and standard deviations (SD) Each Image is Reported to be Visible for the Two 30 second Inspection Periods (1).

	Inspection Periods							
	0 - 30 seconds				30 - 60 seconds			
Image Seen:	LE	SD	RE	SD	LE	SD	RE	SD
Subjects:								
GR	9.16	3.97	9.16	3.29	9.08	7.44	8.61	5.25
SW	14.24	2.83	11.75	1.60	16.19	3.41	12.56	3.04
SK	11.86	2.70	12.15	2.69	15.99	4.31	13.71	3.77
SM	11.05	2.81	5.88	2.65	11.18	4.03	6.09	4.64
GM	10.91	3.98	11.14	3.32	11.19	4.33	21.11	4.35
ID	11.86	3.39	9.30	2.67	17.57	6.24	10.13	5.64
AH	11.22	3.07	11.36	2.19	12.64	3.68	12.83	2.68
CB	12.49	2.08	11.56	2.07	14.57	4.57	13.27	4.13
Mean	11.60		10.29		13.57		12.29	

(1)Mean overall durations refer to the total time within each inspection period the image to the left eye (LE) is visible or the right (RE) averaged over the 6 x 60 second trails in each of the three experimental sessions.

Table 4.2 Mean overall durations (seconds) the image of the left and right eyes were visible and standard deviations (SD) over the 60 seconds of observations.(1)

Subjects:	LEFT EYE	SD	RIGHT EYE	SD
GR	18.24	11.09	17.77	7.24
SW	30.43	4.66	24.31	3.20
SK	27.85	4.16	25.86	3.82
SM	22.23	5.90	11.97	6.86
GM	22.09	4.54	32.25	5.14
ID	29.42	7.70	19.43	8.20
AH	23.86	6.37	24.19	4.18
CB	27.24	4.84	24.83	5.60

(1)Mean overall durations refer to the total time within the inspection period the right or left eye's images were visible averaged over the six trials and three experimental sessions.

4.4. Measures of Ocular Asymmetry

Measures of ocular asymmetry were derived from the overall durations the left and right images were reported to be visible over the 60 seconds of each trial using the formula below:

$$\text{Asymmetry Score} = \frac{LE - RE}{LE + RE}$$

LE = overall duration the left eye's image was visible over the 60 seconds of observation.

RE = overall duration the right eye's image was visible over the 60 seconds of observation.

Ocular asymmetry scores were calculated for each trial (ie. 18) and the mean scores are shown in Table 4.3 together with standard deviations (SD).

Table 4.3 Ocular Asymmetry Scores

Subjects:	Mean asymmetry score	+-1SD
GR	0.10*	0.33
SW	0.12	0.13
SK	0.04	0.11
SM	0.34	0.25
GM	-0.18	0.18
ID	0.23	0.28
AH	-0.02	0.24
CB	0.05	0.14

* Subject GR had expressed difficulty in reporting rivalry with afterimages and had shown a predominantly right ocular asymmetry for the first experimental session and a left ocular asymmetry for the second and third sessions. This subject was given one further experimental session (ie. 6 trials) to investigate the consistency of the asymmetry and this further session resulted in a left asymmetry score. The asymmetry score above is the mean of the trials for the experimental sessions (or days) 2, 3 and 4.

The dominance scores from each 60 second observation trial were entered into an analysis of variance. The factors were: the three experimental sessions and the six trials. There was no significant difference over the experimental sessions (F=2.36, df 2,14, not significant) or trials (F=0.43, df 5, 35, not significant).

4.5. Discussion

After subjects had had sufficient practice at observing afterimage rivalry and had become used to the effect of the flash gun, most subjects commented on the difference between afterimage and real image rivalry. The alternations were slower and composites were reported as being less frequent than was experienced with real image rivalry. However, exclusive visibility was reported for 80% of the observation period (overall subjects) which is less than that reported with real images (87%). The remaining 20% of the observation period is therefore either composites, the time delay between alternating switches or total disappearances, and given the subjects reports it is more likely to be one or both of the latter two factors.

Wade (1974) reported that rivalrous gratings viewed as afterimages and using the same two switch key procedure as used in this experiment were seen as composites for 11.4% of the inspection period. Also both gratings were reported to disappear together occasionally during the observation period. In this study exclusive visibility increased from 75% to 86.2% for the first and second inspection periods respectively. This may reflect a decrease in composites over the viewing period. However, subjects reported infrequent occurrences of composites and this increase may be a function of the initiation of the recording period. The 60 second inspection period began with the discharge of the flashgun although the afterimages were not visible until a short time after the flash.

The duration of each switch depression (the duration of each visible phase of an image) increased in mean value over the two 30 second inspection periods and was accompanied by a decrease in their frequency over the same period. Wade (1975a) reported a similar increase with single line afterimages although the frequency rates were not reported. A decrease in frequency of visibility with real image rivalry occurs when there is a decrease in intensity of the stimuli (Breese, 1899; Kaplan and Metlay, 1964). This may apply to afterimages that were also reported to fade over the 60 seconds of viewing possibly reflecting a decrease in intensity.

There are wide individual differences between subjects on the percentage of time whole images are reported to be visible. There is also some variability over the trials as can be seen from the standard deviations in Table 4.2. When the response patterns for each subject were examined it was found that for some periods only one switch key was depressed either for a long duration and/or for a number of successive short durations while the other image was not reported to be visible at all during this period. This is contrary to Wade's (1975a) suggestion that the disappearance of one image may lead to a long visible period of the other image. The finding reported here indicates that afterimage rivalry is not a clear cut alternation of the two images but that a whole image or part of an image can disappear independently of the phenomenal visible state of the other image. This may have been a contributary factor to the variability in the overall durations each image was reported as visible over the trials.

The asymmetry scores derived from the afterimage measures had a greater range over subjects (-0.18 to +0.34) than those reported with real image viewing (-0.12 to +0.26), although there was also greater variability in the asymmetry scores for afterimages over the trials for each subject. The mean durations of the visible phases were longer with afterimage rivalry (overall mean of 3.87 seconds) than those reported for real images (overall mean of 1.98 seconds). The image on the rivalrous dominant eye had a mean visible phase or duration of 4.33 seconds and the image on the rivalrous non-dominant eye had a mean duration of 3.31 seconds.

Only two subjects in this study have a right ocular asymmetry. If the 20% criterion for rivalrous dominance is applied to the data in Table 4.2, only four subjects have a dominant eye, these are: SW, SM, GM and ID. These subjects were also judged to have a dominant eye using the same criterion with the real image rivalry.

The measures of asymmetry derived from the afterimage experiment that gives both degree and direction of asymmetry are not consistent with the experimental findings on rivalry reported by Wade (1975a) using single line afterimages nor with his hypothesis that postulates two processes to explain the results (1978b). The ocular asymmetry measures are not reduced in this study with afterimages and correlate significantly with the real image measures. This suggests that the basis to the ocular asymmetry measures are not dependent on the differential processes of eye stability and interocular suppression. The asymmetry reported in rivalry may be due to either asymmetrical interocular suppression or possible eye movement factors that are not associated with differential movement of contours over the retinae. The above findings and proposals will be discussed in the following chapter.

CHAPTER 5

Comparison of Afterimage and Real Image Rivalry Measures of Ocular Asymmetry

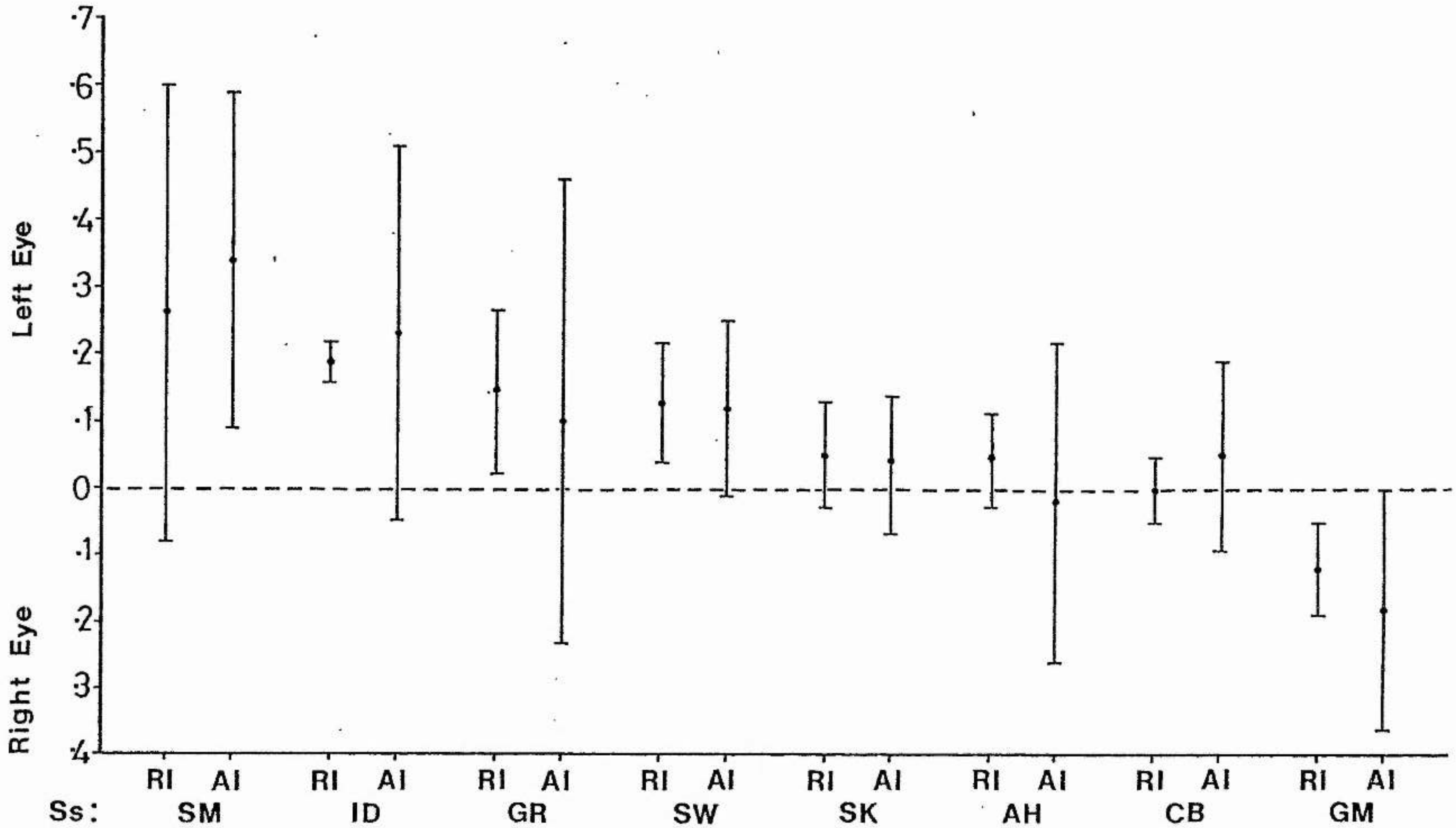
5.1. Introduction

Measures of ocular asymmetry have been reported in chapters 3 and 4 using real images and afterimages in binocular rivalry experiments. The patterns of dominance and suppression differed between the two types; the durations the images were visible were longer for afterimages by a factor of two compared to those for real images and alternations of the two stimuli were slower with after images. Wade (1975a) reported little or no asymmetry between the two images for afterimage rivalry compared to real image rivalry and interpreted his results in terms of the differential involvement of the two processes of ocular stability and interocular suppression. Contrary to Wade's findings (1975a) using rivalrous single lines, measures of ocular asymmetry were recorded in this study with afterimage viewing.

Fig 5.1 shows the mean asymmetry scores and standard deviations (averaged over trials and experimental sessions) for each subject from the two rivalry experiments (chapters 3 and 4). There is close agreement between the mean values of asymmetry although the afterimage scores show greater variability forseven of the eight subjects relative to the real image scores. The correlation coefficient for the two sets of dominance scores is r=0.96 which is significant at the 0.1% level. Fig 5.2 is a scatterplot of these measures.

The close agreement between the measures derived from the two procedures may suggest that there is a common basis to the eye asymmetry findings. The results do not appear to warrant differential explanations involving interocular suppression and eye stability as suggested by Wade (1975a). This is not to suggest that eye movements do not affect or interact with the rivalrous contoured stimuli. Eye movements that occur during real image rivalry viewing may still be responsible for the short visibility durations and quick alternations of the stimuli reported for rivalrous real images (Wade,1974; Levelt, 1967).

Fig 5.1 Ocular Asymmetry Scores and standard deviations (1) for Each Subject derived from the Binocular Rivalry Experiments with Real images and Afterimages. Subjects are arranged arbitrarily in order of decreasing strength of asymmetry of Left Eye.

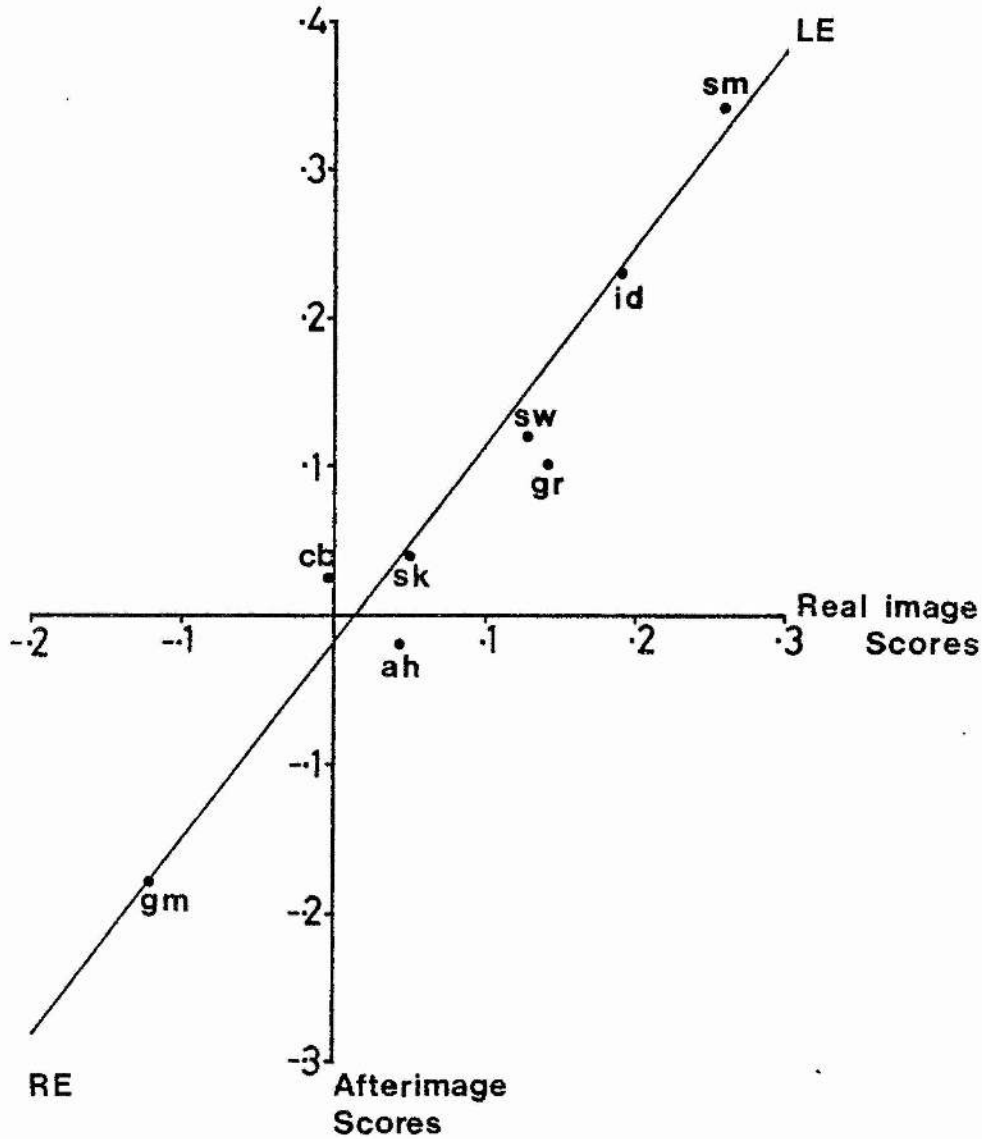


RI - Binocular Rivalry with Real Images (Chapter 3)

AI - Binocular Rivalry with Afterimages (Chapter 4)

(1) The mean asymmetry score is the average of scores from each trial in all experimental sessions

Fig 5.2 Ocular Asymmetry Scores derived from the Binocular Rivalry Experiments with Real Images and Afterimages.



$r = 0.96$, $p < 0.001$

5.2. Discussion

The binocular rivalry measures of ocular asymmetry fail to support the hypothesis outlined by Wade (1978b) or to replicate his findings with rivalrous single line stimuli viewed as both afterimages and real images (Wade, 1975a). He claimed that the ocular asymmetries found with real images were due to greater eye movement instability in one eye relative to the other which interacted with the contours of the stimuli. This process was believed to keep that image in view for longer. However, this hypothesis cannot account for the asymmetry measures reported in this study with afterimages and the close agreement between the measures from the two rivalry procedures.

Differences in eye stability that occur with real image viewing would also be expected with viewing afterimages although contour movement across the retinae would not occur. It is known that eye movements do influence the appearance or disappearance of afterimages: saccades exceeding 1^{o} are known to suppress an afterimage from view (Fiorentini and Mazzantini, 1965; Kennard, Hartmann, Kraft and Boshes, 1970). Movements of this extent would be expected to occur in both eyes and lead to stimultaneous suppression of both images. However, smaller involuntary eye movements in the range 20-30' of arc that occur when fixating a point source have been reported to occur preceding the suppression phase of an afterimage and smaller eye movements of 6' of arc have also been reported to occur preceding the suppression phase. It is not certain if these eye movements contribute to the initiation of the suppression phase (Kennard et al, 1970). However this work on afterimages was carried out using uncontoured stimuli presented to both eyes and not as binocular rivalrous stimuli.

The results reported by Kennard et al (1970) suggest that any asymmetries in relative movement or stability between the eyes would lead to longer periods of suppression of the afterimage in the least stable eye and the image in the most stable eye would be visible for longer. However, given the eye movement hypothesis of Wade's (1978b) the image visible for longer using real images would be expected for the least stable eye. Therefore, if eye movements are directly responsible and afterimages in rivalry are affected by eye movements as described above then the asymmetry measures from the two experiments would be expected to be inversely related.

The relationship between eye movements and the appearance or disappearance of an afterimage during binocular rivalry is not at all clear. Wade (1975c) reported that monocular afterimages were visible for longer in the normally suppressed eye of strabismic individuals and this eye is usually the least stable eye. However, in normals monocularly presented afterimages were visible for longer in the sighting eye relative to that in the non-sighting eye which according to Wade is the least stable eye. Therefore it is not clear what the relationship is between eye movement stability and binocular afterimage rivalry.

In this study the dominant eye with afterimage rivalry was also the dominant eye as measured with the real image rivalry procedure. However, it is possible that binocular interactions between rivalrous afterimages (Wade, 1976b) modify or change the effects of eye movement suppression. To ascertain the effects of eye movements in both measures of ocular asymmetry would require simultaneous eye movement recordings during binocular rivalry with both real images and afterimages. Sabrin and Kertesz (1980) recorded eye movements while subjects viewed real image rivalry between a disc in the left eye and the annulus in the right eye. More microsaccades were reported for the right eye during both the phases of dominance and suppression but these increased during the dominance phase. The right eye in both subjects was also the rivalrous dominant eye. However, the stimuli were not counterbalanced between the eyes and it is not possible to distinguish the effects of differential eye stability or dominance factors from the effect contours and the size the stimuli may have on the durations the images are visible. It is not possible to establish if the increased microsaccadic activity is responsible for the longer periods of dominance of one image or if some other factor is responsible for the difference in performance between the eyes.

Accommodation differences may be considered as a factor contributing to the ocular asymmetry effects in the real image and afterimage experiments. However, Lack (1971) reported no difference in real image rivalry before and after the introduction of 0.5 mm artificial pupils before each eye, nor if the retinal muscles were paralysed. It is not known if the patterns of binocular rivalry would change if these procedures were applied to one eye only. When accommodation is changed the image becomes blurred and Levelt (1966) reported that introducing blur to the left member of a pair of ring-disc rivalrous stimuli made no difference to the rivalry alternations. The contrast was the same in both eyes. It is unlikely that accommodation differences between the eyes can account for the results reported in this study. No report is known of accommodation differences existing between the eyes for binocular viewing.

In this study the image in the rivalrous dominant eye for both types of rivalry was visible for a longer period than the image in the non-dominant eye. The ocular asymmetries may be explained by the inhibitory model of rivalry if the binocular inhibitory effects are asymmetrical. However, it is not known why inhibitory interactions should be asymmetrical.

Wade (1975a) reported that the image to one eye was visible for a longer duration relative to the other with real image rivalry but that this ocular asymmetry was reduced with afterimages. It is not certain why there is a discrepancy between his results and those reported in this study. Single line stimuli were used in his experiment although it is not certain why asymmetries should be eliminated when these stimuli are viewed as afterimages and not when grating stimuli are viewed as afterimages as reported in this study (chapter 4). However, only small numbers of subjects were involved in both studies. Wade (1975a) used only four subjects. Eight subjects participated in this study suggesting that the discrepancy in the results should be interpreted with caution.

CHAPTER 6

Binocular Rivalry with Real Images using Four Response Categories

6.1. Introduction

The pattern of alternations in binocular rivalry is usually measured by depressing switches and it is from this re-description of the perceptual alternations that the process or mechanism of binocular rivalry is inferred. A range of stimuli can elicit binocular rivalry such as orientational differences (Wade, 1974, 1975a) and pattern movement in different directions (Breese, 1899) but not movement per se (Marshuk and Sekuler, 1979). The response categories used to report the stages of appearance and disappearance are provided by the experimenter and usually for eye dominance purposes consist of two response keys or switches, one for the left eye's image and one for the right. Swanston and Wade (1981a) compared the reports of disappearances of simple stimuli under conditions of steady fixation and when viewed as afterimages given two different response procedures. The frequency of disappearances was greater if only one response category was used to indicate disappearance of the whole stimulus compared to the assumed equivalent measure to indicate whole stimulus disappearance derived from the sum of the frequencies of the disappearances of its parts. Therefore different response categories provided by the experimenter to indicate the presence or absence of a percept are not always equivalent (Swanston, 1979; Swanston and Wade, 1981a). In a different study on binocular rivalrous images, Swanston and Wade (1981b) concluded that the response categories used to report alternations may influence the subjective reports of image visibility (possibly directly or indirectly via response bias). From this work conclusions drawn concerning the mechanisms underlying the alternations are called into question.

The measurement of binocular rivalry has been influenced by the classical views on perception and single vision. Rivalry was believed to be an expression of the competition between the eyes and therefore only two perceptual states or responses were considered. Eye dominance or ocular asymmetry reports support this view, one eye is dominant over the other. If only two response keys are used as in the experiments in chapters 3 and 4 caution is required when the nature of ocular dominance and binocular rivalry is inferred from the results.

With the two response procedure 87% of the viewing time with real image rivalry was of one of either whole images. Wade (1975b) used a separate response to record composites and reported that only 58% of the viewing time was of whole images. For smaller gratings this increased to 64% (Wade, 1974) although a two switch procedure was used. Hollins (1980) using a three way toggle switch reported that whole images were visible for only 40-60% of the inspection time. In the previous binocular rivalry experiments the response required to register composites was not compatible with the other response procedures and may have led to some form of response bias and/or an underestimation of the frequency of composites.

This experiment was designed to test the hypothesis that the percentage of composites with real image rivalry would increase if the presence of composites was recorded directly using a compatible response.

The experiment reported in chapter 3 is repeated below with the same group of subjects but composites are recorded by pressing both switches simultaneously. The duration neither switch is pressed is also recorded.

6.2. Method

6.2.1. Subjects

The previous eight subjects participated in this experiment.

6.2.2 Apparatus

The apparatus was the same as that used in the experiment for real image rivalry. The duration and frequency of the left and right switch depressions were recorded as well as the duration and frequency of the simultaneous depression of the two keys and for when neither key was depressed. This is referred to as the four response category procedure.

6.2.3. The Stimuli

The same rivalrous gratings were used as in experiment 3.

6.2.4. Procedure

Subjects participated in only one experimental session of 6 X 90 second trials. Subjects were required to indicate the appearance of composites by pressing both switch keys simultaneously and to press neither switch key if neither grating was visible. One key was pressed to indicate the appearance of one whole grating and the other key for the appearance of the other whole grating.

6.3. Results

Table 6.1 shows the mean overall duration each condition was visible over the 90 seconds of observation over the six trials. It can be seen that composites comprise a higher percentage of the viewing time for each subject compared to the assumed duration reported in the previous experiment (see Table 3.2, p 65). The mean percentage of viewing time whole rivalrous images are visible is 72.8% and composites occupy a mean of 24% of the total viewing time. The remaining 3.2% of the viewing time may reflect the time taken to change from registering one perceptual state to another or possibly total disappearances of the two images. Total disappearances of real images in rivalry have been reported for prolonged viewing (Rainwater and Cogan, 1975).

The overall durations each image was visible within the 3 , 30 second inspection periods, the durations of each switch depression and the frequencies of the visible periods were entered into three separate analyses of variance. The factors were: trials (6 X 90 second inspection periods), and response categories (LE, RE, Composites and "Total disappearances"). (See Appendix D for the summary tables of the analyses of variance and the post-hoc comparison tests using the Scheffé test).

There was a significant difference in the overall durations the four response categories were visible ($F=28.879$, df 3,21, $p<0.00001$). Whole images were visible for longer relative to the other two categories (the difference is 6.67 seconds which is significant at the 1% level). There was no interaction of the four categories with the

Table 6.1 Mean Overall Durations (seconds) and standard deviations (SD) each of the Four Response Categories is Reported to be Visible in the 90 second Inspection Period.

Image Visible:	LE	SD	RE	SD	COMPOSITES	SD	Tt.DISAPP.	SD
Subjects:								
GR	33.89	3.00	30.85	2.75	19.82	1.82	2.57	1.53
SW	38.16	4.85	28.36	3.76	22.40	7.05	1.08	0.65
SK	38.02	3.09	39 37	2.71	11.46	1.96	1.16	0.20
SM	-40.35	6.42	36.19	1.10	12.59	5.93	0.90	0.44
GM	26.81	4.08	33.75	5.39	28.77	6.07	0.70	0.40
ID	19.49	9.67	21.06	4.26	38.07	17.90	1.14	1.09
AH	31.12	4.14	33.62	2.13	22.02	4.33	3.24	3.06
CB	37.44	2.99	35.38	1.84	15.82	1.78	1.35	0.46
Mean	33.16		32.32		21.37		1.52	

LE - the duration the image to the left eye is visible.

RE - the duration the image to the right eye is visible.

Tt.DISAPP. - "total disappearances".

trials or three 30 second inspection periods. This pattern was also mirrored in the mean durations of the dominance or visible phases ($F=5.10$, df 3,21 , $p<0.008$), these were 1.47, 1.59, 0.97 and 0.58 seconds for the left eye's image, right eye's image, composites and "total disappearances" respectively. The left and right eye whole image responses were significantly longer than the two other categories (the difference is 0.76 seconds which is significant at the 5% level). There was no significant variation of these durations over trials.

The four categories differed significantly in the frequency that they were reported to be visible ($F=46.9204$, df 3,21, $p<0.00001$). The left and right eye whole images (mean value of 21 combined) were reported only two thirds as frequently as composites (mean value 33) and "total disappearances" occurred with a mean frequency of 3 throughout the 90 second observation period.

It can be seen from Table 6.1 that the overall durations the left and right eye's images for each subject were reported to be visible were different but when averaged over subjects the difference was not significant as would be expected from a group of subjects with mixed degrees of asymmetry (difference is 0.26 seconds ,not significant).

6.4. Measures of Ocular Asymmetry

Measures of ocular asymmetry were derived from the overall durations each image was reported to be visible in each 90 second trial using the formula on page 66. A mean asymmetry score was derived from these six scores for each subject and are shown together with standard deviations (SD) in Table 6.2.

Table 6.2 Ocular Asymmetry Scores

Subjects:	Mean asymmetry score	+-1SD
GR	0.05	0.09
SW	0.147	0.08
SK	-0.017	0.07
SM	0.05	0.09
GM	-0.115	0.11
ID	-0.09	0.28
AH	-0.042	0.05
CB	0.027	0.07

Four subjects have a left ocular asymmetry and four subjects have a right ocular asymmetry. The mean degree of asymmetry is 0.067 if the direction of the asymmetry is ignored.

6.5. Discussion

In this study on binocular rivalry a response category was provided to directly measure the occurrence of composites. Composites were recorded for 24% of the observation period compared to the assumed 13% reported in the previous real image rivalry experiment which used an indirect or less compatible response mode. The 24% compares more favourably with reports from other studies that have used rivalry with real images (Wade, 1974; Hollins, 1980).

There was no significant change in the overall durations of the four response categories over the three thirty second inspection periods. This suggests that the provision of only two responses for whole image registration together with an incompatible response for registering composites induces a response bias such that whole images are recorded with increasing durations over the observation period. Inspection of the rivalry patterns for each subject indicate that composites are a transitory state between the visible phase of the image in one eye and that in the other. This is further supported by the high frequency of composites and their short durations relative to the other two categories. This suggests that rivalry suppression may not be an all or none state as has been claimed (Blake and Camisa, 1979, p 323; Blake and

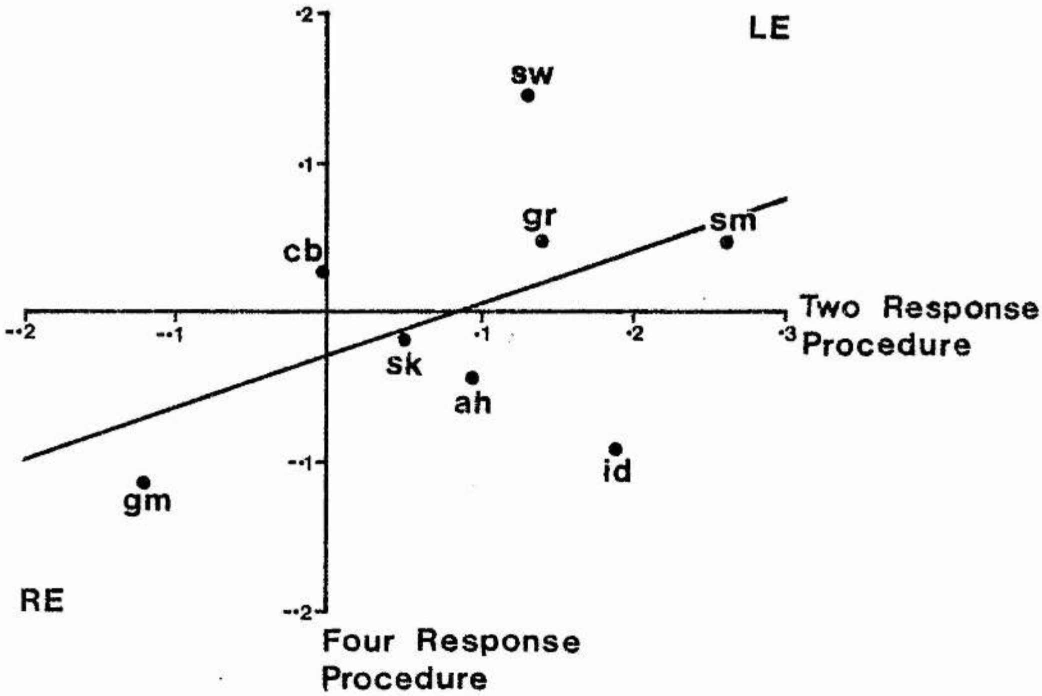
Fox, 1974a).

The visible periods or dominance durations were overall shorter than those reported in the previous experiment. This suggests that composites may have been classed with whole image reports in the last experiment thereby increasing the durations these two categories were reported to be visible. The results from this experiment support the view that composites are a valid perceptual category in binocular rivalry and may reflect a period of partial suppression between the changing phases of dominance and suppression (Panum, 1858; Ogle and Wakefield, 1967). This same procedure was not carried out with afterimage binocular rivalry although subjective reports from the study in chapter 4 and reports from other studies (Wade, 1974) would suggest that composites occur less frequently with afterimage rivalry. The difference in composite frequency between real and afterimage rivalry may be due to the rapid alternation of real images possibly due to eye movements (Wade, 1974).

The asymmetry scores from this procedure were compared to the asymmetry scores from the real image rivalry experiment using the two switch key procedure (chapter 3). Fig 6.1 shows a scatterplot of these scores. The asymmetry scores in this present study were smaller, with an overall mean of 0.067 (ignoring the sign) compared to the mean asymmetry of 0.12 for the same subjects in the previous experiment. The range of scores in this experiment is also smaller, -0.12 to +0.15. Four subjects are classed as having a right ocular asymmetry and it can be seen from Fig 6.1 that there is a slight shift of the asymmetry measures from the previous experiment to those in the present towards the right eye. The correlation coefficient for the two sets of scores is $r = 0.45$ which is not significant. Three of the four subjects, SK, AH and CB who show a change in the direction of ocular asymmetry between the two procedures have the lowest degrees of asymmetry in both experiments.

The weak relationship of the asymmetry measures from both procedures may reflect either a change in the direction of the asymmetry over time (there was a three month interval between the two experiments) or the procedure adopted in the previous experiment (using two switch keys) induced a response bias. Composites in the previous experiment may have been reported as belonging to a whole image category thereby increasing

Fig 6.1 Ocular Asymmetry Scores for Eight Subjects from the Real Image Binocular Rivalry Experiment Using the Two Different Procedures of Response Categorisation.



r = 0.45, not significant.

the asymmetry towards one eye. The decrease in the strength of the ocular asymmetry measures together with the slight shift in direction of the asymmetry does suggest that a response bias may have been operating in the previous experiment. If the 20% criterion for eye dominance is applied to the results in Table 6.1 only two subjects are judged as having a dominant eye (subjects SW and GM) compared to four subjects in the experiment in chapter 3.

The small range of asymmetry scores and the frequency of composites reported in this study suggest that the term eye dominance is not appropriate to describe the differences in the durations the left and right images are reported to be visible. The results show there is an asymmetry in the durations towards one eye relative to the other. The term eye dominance as applied to binocular rivalry measures has arisen from the theoretical view of the role of suppression in binocular vision ie. of all or none suppression of one or other image. This in turn has influenced the procedure adopted to measure it, ie. use of two responses to register the phenomonal alternations between the left and the right eye's images. The "dominance" of one eye over the other in the above procedure is less marked, rather there is an asymmetry in the binocular rivalry recordings towards one eye.

CHAPTER 7

Conclusions and Sighting Dominance

7.1. Introduction

Sighting tasks were the earliest form of eye dominance tests mentioned in the eye dominance literature and also in relation to singleness in binocular vision (Porta, 1593). More attention has been directed to sighting dominance than to any other type of ocular dominance, and it has formed the basis to one of the theories of ocular dominance (Walls, 1951; Rubin and Walls, 1969). In sighting tests objects in space are positioned colinear with one eye and it was believed that in binocular vision visual directions were judged only by the sighting eye (Parson, 1924; Walls, 1951). The sighting eye was believed to have motor superiority such as greater neuromuscular stability relative to the non-sighting eye (Ogle, 1962).

There are many variations of sighting dominance test eg. those involving visual alignment, visual sighting, alignment of part of the self with an object and pointing an object at the self. Despite the belief that the variety of sighting tests were measuring the same underlying factor, ie. sighting dominance, there have been reports of low correlations between them. Buxton and Crosland (1937) reported a correlation coefficient of 0.45 between reports from i) aiming a gun at an object and ii) alignment of a rod with a distant object for 86 subjects.

Low correlations have also been reported between sighting dominance and the rivalry dominance tests. (Coren and Kaplan, 1973; Gronwall and Sampson, 1974). Gronwall and Sampson (1974) reported a correlation coefficient of 0.28 for 50 subjects between results from a battery of rivalry tests and results from a battery of sighting tests. The poor relations between the two types of measures have been interpreted as evidence for the division of sighting and rivalry dominance on motor and sensory factors respectively. The division of rivalry and sighting dominance in the literature has persisted despite the study of binocular rivalry as the possible underlying process in binocular single vision;

the rivalrous dominant eye processes the visual direction of objects in space (cf. the sighting eye vs the cyclopean eye hypothesis).

The assumed independence of the two measures encouraged investigations into the factors that were responsible for rivalry dominance and factors responsible for sighting dominance. The continued use of the dichotomous classification tended to obscure any analytical approach. Wade's (1978b) hypothesis was one explanation for the discrepancy of rivalry and sighting dominance results in the literature. He (1978b) suggested that there were two processes involved; interocular suppression and ocular stability. The rivalry and sighting tasks were differentially weighted on these factors. In a sighting task, the more stable eye will be favoured as the sighting eye, and in a rivalry test the less stable eye will become the dominant eye.

However, it is possible that suppression also occurs in sighting tasks. The large disparity of the non-fixated target will be experienced as double and if one of these double images is dominant or more prominent than the other, due to interocular suppression, it may be the image chosen for alignment. The sighting dominant eye therefore is dependent on the "sensory" dominant process.

Two experiments on sighting dominance are reported in this chapter for the same group of subjects who participated in the previous rivalry experiments. The experiments were designed to test:

i) The incidence of sighting dominance.

ii) Wade's hypothesis (1978b) that sighting and rivalry dominance are inversely related (using the dichotomous classification).

7.2. Method

7.2.1. Subjects

The same eight subjects that had participated in the experiments in chapters 3, 4 and 6 took part.

7.2.2. Apparatus

a) The Modified Miles's A-B-C test (Miles, 1929)

A triangular shaped cone was mounted on an horizontal rod which was attached at the apex by a joint to allow lateral movement only. A chin rest and head board was positioned such that the apex was on the midline with the intersection of the eyes. A white marker was placed 3' away on the wall such that it appeared in line with the midline of the cone and the point midway between the eyes.

b) The Point Test (Porta, 1593)

A white bar marker was placed on the wall 8' away from the subject for alignment with the subject's finger.

7.2.3. Procedure

a) Subjects were required to look down the cone at the facing wall and move it laterally until the white marker could be seen through the small aperture at the apex. The lateral position of the cone was noted after the subject had made the sighting. Six trials were given and the cone was positioned off the midline before each trial. Both eyes remained open during all trials.

b) Subjects were asked to placed the tips of the left and right fingers together and align the finger tips with the white bar marker on the wall. Both eyes remained open. The experimenter covered one eye of the subject and asked if the fingers remained aligned with the white bar. If the fingers remained aligned the uncovered eye was designated the dominant eye, if the fingers were not aligned, the covered eye was designated the dominant eye. Only one alignment was made.

7.3. Results

Table 7.1 shows the results from each trial of the cone test and the results of the point test. Subjects were classified as being either left eye dominant or right eye dominant.

Table 7.1 Eye Dominance Classification for Two Sighting Tests

	Miles's Cone Test						Point test
Trials:	1	2	3	4	5	6	
Subjects:							
GR	LE	LE	LE	LE	LE	LE	LE
SW	RE	RE	RE	RE	RE	RE	RE
SK	LE	LE	RE	RE	RE	RE	RE
SM	LE	LE	LE	LE	LE	LE	LE
GM	RE	LE	RE	RE	RE	RE	RE
ID	-	-	-	-	-	-	-
AH	LE	RE	LE	RE	RE	LE	RE
CB	LE	LE	LE	LE	LE	LE	LE

LE = sighting or alignment with the left eye

RE = sighting or alignment with the right eye

7.4. Discussion

Subject ID expressed difficulty in performing both sighting tests with both eyes open. Although he did move the cone so that the white marker was aligned he was never satisfied with the setting. This subject was therefore judged to have no sighting dominance. Barbeito (1981) also reported one subject with no sighting dominance. Four of the remaining seven subjects are consistent with their sighting eye. Subjects SK and GM sight with the right eye more often on the trials for the cone test and also on the point test. Using a similar procedure of classification as adopted by Coren and Kaplan (1973) these subjects are designated as being right eye dominant. Similarly subject AH is classed as having a right dominant eye.

The sighting dominance results also indicate a lack of consistency over trials for the same test and between two tests that are assumed to measure the same construct i.e. sighting dominance.

7.4.1. Comparison of Rivalry Measures of Ocular Asymmetry with Sighting Dominance

Table 7.2 shows the dichotomous classification of the sighting results and the direction of asymmetry from the binocular rivalry experiments (chapters 3, 4 and 6)

Table 7.2 Eye Dominance Results

SUBJECTS:	GR	SW	SK	SM	GM	ID	AH	CB
SIGHTING DOMINANCE	LE	RE	RE	LE	RE	RE/LE	RE	LE
REAL IMAGE RIVALRY	LE	LE	LE	LE	RE	LE	LE	RE
AFTER IMAGE RIVALRY	LE	LE	LE	LE	RE	LE	RE	LE
REAL IMAGE* RIVALRY(ch.6)	LE	LE	RE	LE	RE	RE	RE	LE

* Real image rivalry results from the four response procedure experiment.

Three subjects show a consistent dominance of one eye on all three tests. For three of the seven subjects the rivalrous dominant eye is the sighting eye (this is comparing real image rivalry using two responses) and this increases to five out of seven for afterimage results. Using the results from the four response procedure, six out of the seven subject show a positive relationship between sighting dominance and rivalry dominance. These results do not support the hypothesis of Wade (1978) which predicts an inverse relationship between rivalry and sighting measures of dominance.

It is interesting to note that subject ID experienced a high percentage of composites with both the real image rivalry experiments, as well as experiencing difficulty in performing the sighting tasks. This suggests that the sighting measures are insensitive to small amounts of ocular asymmetry because of the reliance on one eye to perform the task.

Given the criticisms directed at comparisons made between the two measures using a dichotomous classification the mixed results should not be given too much emphasis. Similar mixed findings have been reported by Lack (1973). The asymmetry measures for several of the subjects are small (eg. SK, AH and CB) and it is misleading to classify these results dichotomously. The inconsistency of the sighting reports also indicates that the nature of the test is insensitive to small ocular asymmetries and imposes a false dichotomy.

7.5. Conclusions of Part II

7.5.1. Binocular Rivalry Measures of Ocular Asymmetry

Eight subjects participated in binocular rivalry experiments measuring ocular asymmetries using 1.25° diameter oblique orthogonal gratings. An asymmetry in the durations each image was recorded as visible was found for i) the duration of each visible phase, and ii) the overall total duration each image was visible over the inspection period. A measure of asymmetry was derived based on these latter figures by taking the difference in overall durations for the two images, one for the right eye and one for the left, and dividing the difference by the sum of the two. This asymmetry score gave the direction and degree of asymmetry placing subjects along an interval scale from -1 (total dominance of the right eye) through zero (no asymmetry) to +1 (total dominance of the left eye).

In chapter 3, binocular rivalry was reported with real images. Exclusive visibility (that is, the whole left image or the whole right image) was reported for a mean of 87% of the viewing time. The visible phases of whole images tended to increase over the inspection periods. This finding may be explained by either i) a decrease the intensity of the images with prolonged viewing, possibly leading to an increase in whole image visibility or ii) an increase in the bias towards reporting whole images at the expense of composites over the observation period. Measures of asymmetry were derived using the above procedure. The asymmetry scores were small and if the 20% criterion was used (Washburn, Faison and Scott, 1934) only four subjects could be classed as having a dominant eye. These dominance scores were fairly consistent over the trials and experimental sessions. It was concluded that binocular rivalry could be used as a measure of ocular asymmetry.

In chapter 4, afterimage rivalry was reported for the same group of subjects. Alternations of the images were slower and "crisper", subjective reports indicating that composites were few despite the rivalry recordings indicating exclusive visibility for only 80% of the inspection period. The remaining 20% assumed to be composites may also have included total dis appearances that were reported as being more frequent with afterimage viewing (Wade, 1974, 1978a). There was greater variability over the trials for the durations afterimages were reported as visible and it was suggested that the visible phases of one afterimage may be independent of the visible/invisible state of the other one. Asymmetry measures were derived as above and again were quite small but not noticeably less than those found with real images. This finding did not support the hypothesis of Wade (1978b) nor agree with his previous finding (1975a) that dominance effects are reduced with afterimage viewing.

In chapter 5 the relationship between the two sets of rivalry measures was reported. There was a highly significant correlation between the real image and afterimage rivalry scores. It was concluded that it was not necessary to postulate the differential involvement of two processes to explain the asymmetry results from the two procedures (Wade, 1975a, 1978b).

In chapter 6, real image rivalry was repeated using a different procedure to report the alternations. Three responses were provided, one each for whole images and a third for composites, "total disappearances" were also recorded by the computer. The percentage of composites over the inspection period using a direct response increased to a figure of 24%. There was no significant change of this category over the inspection period suggesting that the increase in exclusive visibility observed in the experiment in chapter 3 may be due to response bias. The high frequency of composites suggests that combinations of the two images is a valid percept in rivalry and needs to be considered and incorporated into any model of binocular rivalry. This phase may reflect partial suppression of the images, and/or a transitory stage in the change from dominance to suppression (Panum, 1858; Ogle and Wakefield, 1967). Eye dominance measures derived from this procedure were smaller than those reported in chapter 3. There was a weak relationship between the two sets of real image rivalry measures. Subjects who had a weak asymmetry score in the previous study tended to show a small shift in the direction of asymmetry (mainly towards the right eye) with the new procedure. The scores for these subjects still remained small relative to the other subjects results. Similar measures of asymmetry have been reported by other authors using a different dichoptic viewing procedure. The same formula as used in this study was adopted to derive a measure of ocular asymmetry and the majority of subjects had small asymmetry scores with only a third of the subjects showing extreme dominance (Perry and Childers, 1972; Ondercin, Perry and Childers, 1973). These authors used a different dichoptic viewing procedure. Letters were briefly presented dichoptically and subjects were required to recall as many letters as possible from each eye. The majority of subjects fell in the centre of the distribution. If a dichotomous procedure was adopted for the Ondercin et al (1973) results and for those in this study any small variability in the asymmetry scores with an increased number of measurements might shift the asymmetry from one eye to the other.

In chapter 7, sighting dominance was measured using two tests, the point test and the cone sighting test. The results for the cone test were not consistent over the trials for all the subjects nor were these in full agreement with the point test. One subject had no sighting dominant eye. These results were compared with the asymmetry measures from the rivalry experiments. The real image rivalrous dominant eye (two response procedure) agreed with the sighting dominant eye for three subjects and with the afterimage rivalrous eye for five subjects. This increased to six out of seven for the four response procedure using real images. Wade's (1978b) hypothesis would predict that the two would be inversely related because of the differential weighting of the tests on eye stability and interocular suppression. The results in this study were not conclusive. However, it was concluded that a comparison between rivalry dominance and sighting dominance using the dichotomous classification adds little to the understanding of ocular asymmetries in binocular vision.

This suggests that binocular rivalry as a measure of dominance cannot be used with a dichotomous classification for comparison with sighting results. The small dominance measures and the high percentage of composites suggests that the term ocular asymmetry should be used instead of the term eye dominance that carries the connotation of eye competition. It must be recalled that if rivalrous stimuli are increased in size, the appearance of whole images breaks down to a piecemeal suppression and dominance of the two images. Therefore a positive relationship between ocular asymmetries derived from rivalry and the sighting dominance results would not be expected and that a comparison between the two dominance measures does little to further the understanding of dominance effects in binocular vision.

7.5.2. Rivalry Suppression , Sighting Dominance and Single Vision.

The role of binocular rivalry in single vision and in the suppression theories was outlined in the introduction to Part II. The suppression theory in its strongest form claims that visual directions of objects are specified by the eye that is dominant in binocular vision (Verhoeff, 1935; Asher, 1953). Binocular rivalry is assumed to occur in normal vision. The classical approach to rivalry and rivalry dominance is that one whole eye specifies the visual direction of objects in space. This is assumed to alternate between the eyes, just as the appearance of the two images alternate in rivalry. Illusory motion would be expected but this is not experienced.

However, the visual directions of objects in space are also assumed to be specified by the sighting dominant eye (Walls-Ogle hypothesis, see pages 12-18). This hypothesis has been criticised in the Introduction (chapter 1) in relation to Hering's principles of visual direction (Hering, 1879/1942; Howard and Templeton, 1966). When the eyes are symmetrically converged , an object is usually judged with reference from a point midway between the eyes, the cyclopean eye or egocentre. An object that stimulates the foveae of both eyes is judged as if seen by an eye assumed to be midway between the eyes, on a line passing through the point of fixation of the two visual lines and the egocentre. Objects on the visual line of one eye are judged as if from this median plane in the head even if the object seen by the other eye is obscured. Thus it is not the sighting eye that specifies the visual direction of objects but the egocentre. It is the nature of the sighting test that gives the impression that it is this eye in binocular vision that performs the alignment (Barbeito, 1981).

The role of the sighting dominant and rivalry dominant eyes has been assumed to be similar in binocular vision although the nature of the tests have obscured any relationship between suppression and alignment behaviour. When objects have a zero disparity, the images are corresponding and have one visual direction with reference to the egocentre. However, with disparate images the visual direction may correspond to one of the monocular images or the average of the two oculocentric or monocular specified directions. The work of Ono et al (1977) demonstrated that suppression of one image or the "fusion" of the two images was dependent on the stimulus variables involved. For small disparate stimuli the visual direction was intermediate of the two monocular images (also supported by the Sheedy and Fry study (1979)) and for large disparate stimuli one monocular image temporarily dominated, or double images occurred. In a sighting task, the object not fixated has a large disparity and is seen double. It has been suggested that sighting behaviour is the habitual choice of one of these images over the other (Howard, 1982). However, Barbeito (1981) found the processing of visual direction was dependent on the location of the egocentre and the sighting eye was the eye nearest to the egocentre. Thus the egocentre for some subjects was to one side of the point midway between the eyes (Pickwell, 1972, 1973) although it is not certain how or why this should be the case. The use of dichotomous classifications for both rivalry and sighting is misleading, especially if the ocular asymmetry as found with rivalry is small and it is the egocentre that specifies visual directions of objects.

Both eyes are involved in the processing of visual directions of objects in space. Dominance of one eye or monocular viewing was proposed by the early theorists as the process responsible for single vision. Continued use of these tests of eye dominance that rely on monocular testing or that postulate competition between the eyes add little to the understanding of the interaction of the two eyes in binocular vision or to the nature of ocular asymmetries. It is proposed that the term ocular asymmetry is adopted to describe the binocular rivalry results and the asymmetries in the performance of the two eyes reported in the following chapters.

PART III

DEPTH DISCRIMINATION MEASURES OF OCULAR ASYMMETRY

CHAPTER 8

8.1. Introduction

In Part II a binocular rivalry paradigm was used to derive a measure of ocular asymmetry using both real images and afterimages. However, this dichoptic viewing paradigm necessarily involves some form of competition between the images seen by the two eyes. Asymmetry in eye performance has also been reported in other studies using other dichoptic viewing paradigms that do not involve phenomenal rivalry. Perry and Childers (1972) developed a measure of eye dominance using briefly presented identical or competing alpha-numerics dichoptically to the two eyes. The letters reported by each eye over repeated trials were used to derive a dominance score. The dominance score for 56 subjects approximated a normal distribution. However, the degree of dominance was susceptible to changes in image clarity (Ondercin, Perry and Childers, 1973). Dominance strength was reduced if the image in the dominant eye was blurred during binocular viewing but enhanced if the image in the non-dominant eye was blurred. However, monocular presentation of the stimuli and blur by the most powerful lens (+2.25D) reduced the percentage correct by only 10% in both eyes. This indicates that these dominance effects involve binocular interactions and it is not due to inability to discriminate the material.

Asymmetries between the eyes have also been reported for suprathreshold contrast matching and luminance matching experiments (Levelt, 1965; Legge and Rubin, 1981). Also in masking studies it was found that the severity of the mask on the target was dependent on which eye received the mask and which eye received the target (Turvey,1973). Greatest stimulus degradation was reported if the dominant eye received the mask. This asymmetry was found to be unrelated to further dichoptic recognition tasks such as recall of letters from briefly presented letters displayed dichoptically (Monohan and Steronko, 1977). The threshold test probe technique has also revealed threshold sensitivity differences between the eyes in binocular viewing (Cogan and Silverman, 1980).

This difference in "sensitivity" may reflect a difference in processing speed as has been suggested by the studies on masking (Legge, 1979; the latency hypothesis). The dominant eye is assumed to process signals faster or have quicker response characteristics than the other. Binocular interaction takes the form of meta-contrast matching, the stimulus from the dominant eye arrives at the binocular site before the weaker or slower stimulus and inhibits or masks it.

Reaction times to discriminate or detect a stimulus such as a light flash is assumed to indicate the perceptual strength of a stimulus. Stimuli that have equivalent response times are taken to have the same perceptual strength (Munucci and Connors, 1964; Mansfield, 1973). Reaction times have been used to investigate binocular interactions for supratheshold stimuli (Harwerth, Smith and Levi, 1980). In this study (Harwerth, Smith and Levi, 1980) criterion response latencies were recorded for contrast gratings presented monocularly or binocularly. At near contrast threshold, monocularly presented gratings required 40% to 70% more contrast than binocular ones. At high contrasts, there were wide individual differences, some subjects required less contrast for the monocular gratings in order to obtain equivalent response times, others requiring more. However, this study and other studies on binocular interactions do not demonstrate how the binocular percept is dependent on the monocular components. "Is the binocular percept disproportionately dependent on one eye's input, ie. the dominant eye?"

The binocular rivalry experiments with small non-disparate stimuli demonstrated that one eye dominates the other for a slightly longer duration. These results together with asymmetries found in the above binocular summation experiments and binocular matching studies would suggest that similar asymmetries might be found with disparate stimuli. No study has so far been reported that has investigated ocular asymmetries using a binocular viewing paradigm involving depth perception. The experiment reported in the following section is an investigation into asymmetries in binocular vision using a stereoscopic viewing paradigm with selective attenuation of the displays to the two eyes.

Random-dot stereograms were used as the stimuli to produce the stereoscopic depth effect. Binocular fusion and depth in these stereograms involves the stereopsis mechanism which can be regarded as a co-operative phenomenon. The inputs from both eyes are compared and are necessary for stereopsis to operate.

8.2. Random-dot Stereograms as a Research Tool

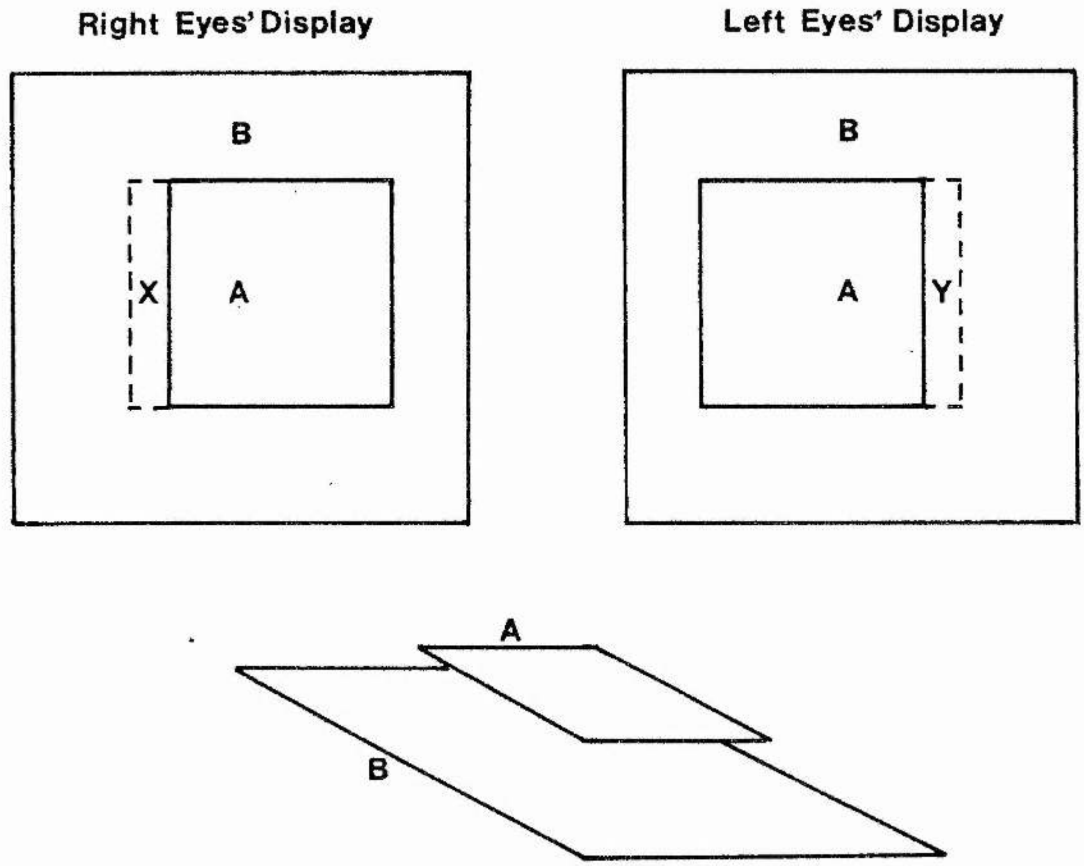
Random-dot stereograms were introduced by Julesz (1960) and have stimulated renewed interest into stereopsis. Random-dot stereograms are composed of two identical matrices of dots, one for the left eye and one for the right eye. An identical area in each matrix is then shifted in an opposite direction in each display (see Fig 8.1). The remaining gaps are then filled in with more random dots. The area that has been shifted is impossible to detect with monocular viewing of either or both displays. However, when the left and right displays are viewed by the left and right eyes respectively and the displays are fused, the area that has been shifted appears to lie above the surround coming out in depth or to recede in depth depending on the direction the areas have been shifted.

Only when the two displays are fused and processed by the stereopsis mechanism can the form or shape of the object be recognised. Thus, monocular pattern recognition is not a necessary prerequisite to binocular fusion and stereopsis.

Julesz and other investigators have exploited the monocularly unidentifiable properties of the random-dot stereogram technique in the study of stereopsis and for tracing the flow of information in the visual system (see Julesz, 1971). Visual phenomena (for example, illusions) have been presented in the form of random-dot stereograms and their strength measured. If the visual effect is as compelling in this form as when presented in the classical form then the assumption is made that the mechanism responsible for the phenomenon lies at or after the site of binocular combination. If the visual effect is weakened or lost then part or all of the mechanism is assumed to lie at a site peripheral to binocular combination.

Any model of the visual system must be able to explain that with random-dot stereograms, stereopsis is always experienced with fusion. This contrasts with classical stereograms, depth is reported even if two disparate lines are experienced as double (Ogle, 1953). Random-dot

Fig 8.1 Diagram to Show How a Stereogram Portraying One Square Area of Convergent Disparity is Made.



An identical square area of dots (A) in each display is moved in opposite directions to each other leaving two gaps X and Y. These are filled in with a random configuration of dots. When the right and left displays are fused, the square area A appears to stand in front of the surround B.

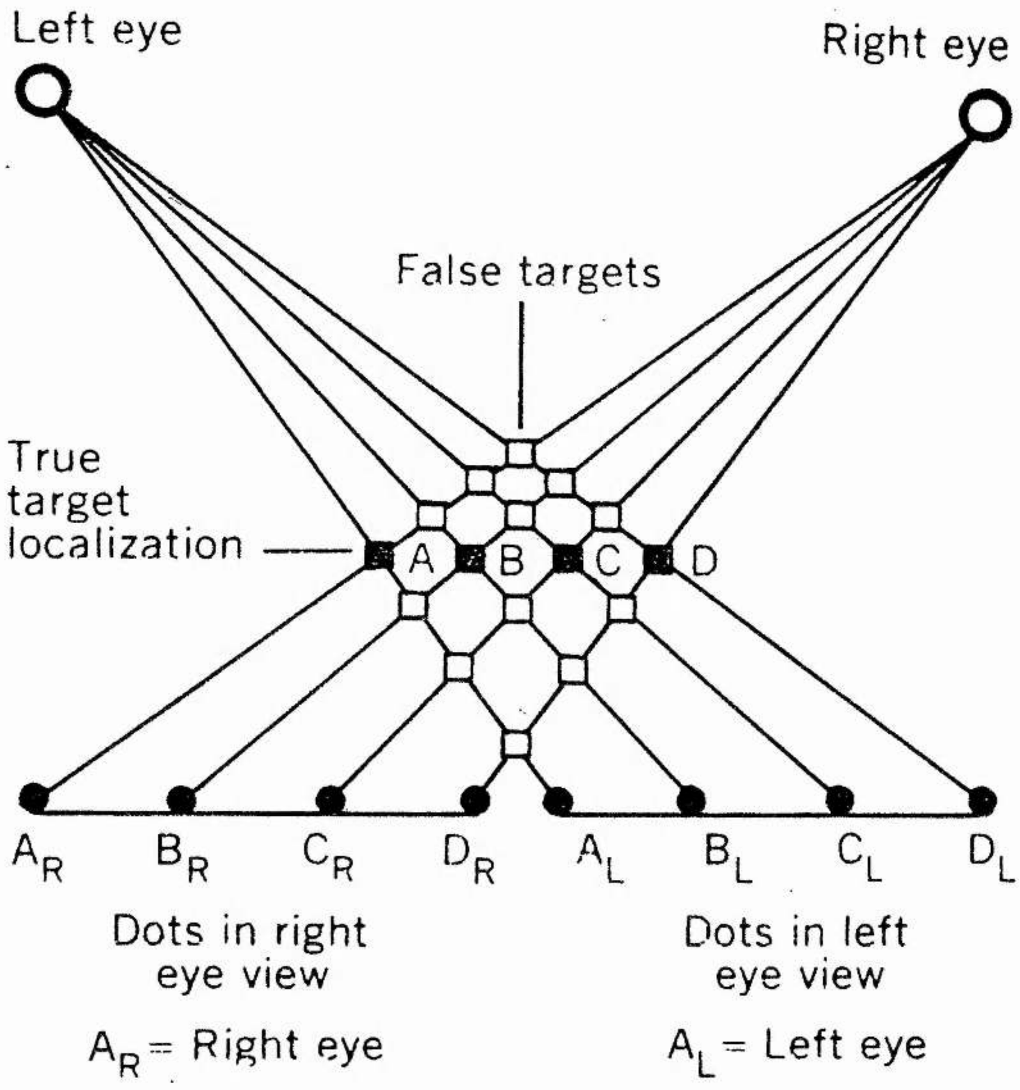
stereograms possess many inherent ambiguities for fusion, and many theoretical fusions are possible between the random dots of one display with those of the other (see Fig 8.2). If fusion is not achieved the correct stereoscopic percept is not obtained.

Any model of stereopsis must be able to accommodate the inherent ambiguity in random-dot displays. Construction of models for the simulation of the stereopsis mechanism represent conceptual aids for predicting and understanding how fusion and depth are performed by the visual system. These models are briefly outlined below to illustrate some of the problems in stereoscopic vision that the models must be able to deal with.

Correct fusional solutions are made despite the many theoretical matches that exist. Julesz (1971) proposed a hardware model to represent the fusional process of stereopsis. This model was based on hypothetical magnetic dipoles connected by springs. Stereoscopic fusion is believed to be a co-operative process, the global percept or organisation of the fused depth plane is achieved by local interactive processes that co-operate to bring about the correct fusional solution. Nelson (1975) proposed a physiological model or mechanism which is an extension of the co-operativity between local disparity detector units (magnetic dipoles) proposed by Julesz. These models process many disparity values. The models of Nelson (1975) and others; Sperling (1970), Dev (1975), Sugie and Suwa (1977), imply the existence of many different disparity detectors (apart from the dipole model where disparity is coded by the degree of orientation of the dipoles).

Eye movements have been reported to be essential for depth perception in some random-dot stereograms, especially in complex random-dot stereograms, portraying many depth planes (Frisby and Clatworthy, 1975; Saye and Frisby, 1975). For stereopsis in the disparity range 0-13' of arc (Mayhew and Frisby, 1979) eye movements are not necessary. Richards (1970, 1971) proposed a stereopsis model based on his observations and experiments with stereo-anomalous observers. The model has three pools of disparity detectors, uncrossed, zero and crossed disparity pools and some stereo-anomalous observers are assumed to have one or more non-functioning or non-existent pool of disparity detectors.

Fig 8.2 Diagram to Show the Inherent Ambiguity in Random-dot Stereograms and the problem of achieving the correct match (taken from Julesz, 1971,p.119).



Each of the four dots in one eye's view can be matched with any of the four dots in the other eye's view making 16 possible localisations of the targets. There are four true target localisations and 12 false ones.

Independent spatial frequency tuned stereopsis channels have been proposed that reduce the the problem of false targets (see Fig 8.2) that occur in the matching process or fusional process of random-dot stereograms (Julesz and Miller, 1975; Mayhew and Frisby, 1976). The Marr and Poggio (1979) computational model proposed that fusions between the left and right displays were made in spatial frequency tuned stereopsis channels with a disparity range tied to the spatial frequency sensitivity. Thus the range within which disparity measurements are made and false targets eliminated is reduced. Eye movements are essential for each part of the stimulus to be brought within the small disparity range for processing by the high resolution channels. The computational model proposed by Mayhew and Frisby (Mayhew and Frisby, 1978, 1980) does not assume that the disparity range is associated with spatial frequency channels. Matches between the two visual fields are not made independently in each spatial frequency channel. Global disparity and early symbolic descriptions of a scene share the same neural elements and both co-operate to disambiguate the processing of the scene into figure/ground and depth planes.

8.3. Modifications of the Stereoscopic Stimuli

The stereoscopic depth effect can still be appreciated in random-dot stereograms despite modifications made to one or other stereo display. Depth does not occur with opposite contrast stereograms (Treisman, 1962; Julesz, 1963, 1971; Levy and Lawson, 1978) although it does occur with a 3 log unit difference in luminance between the two stereo fields (Rogers, 1976). Blurring or expanding one stereo display by 15% does not destroy stereopsis (Julesz, 1971). Similarly, if 20-30% of the dots in the stereogram are complemented stereopsis still occurs (Julesz, 1971). Depth also occurs with rivalrous stereoscopic displays (Julesz and Miller, 1975; Kaufman, 1974). This demonstrates that the stereopsis mechanism is quite robust and insensitive to major perturbations although a 3 log unit difference does create an "unstable" depth effect.

Similar findings have been reported for classical stereoscopic stimuli. Using a three-rod procedure to measure stereoacuity, Lit (1959) reported that unequal luminance did not affect the stereoacuity measures. Similarly, Mitchell (1970) reported that for static displays, objects were correctly localised in depth if there was a luminance difference of 1.6 log units, as long as they were above threshold. Ogle and Groch (1956) reported successful discriminations of depth planes in displays with luminance differences between the two stereo images. Depth is still seen if there is an interocular delay between the onset of the two stereo fields by 75-100 ms (Mitchell, 1970) a result also supported by Ogle (1963). However, stereoacuity does appear to be influenced by degradation in the spatial characteristics of the images. Westheimer and Mckee (1980) briefly presented three lines, the central line was disparate and subjects were asked to report the position of the centre line as "in front" or "behind" the reference lines in order to attain a 75% correct level. If blur was introduced to one image (a refractive error of +- 0 to 3D) stereoacuity was degraded and this decrement was equivalent and sometimes greater than if the same amount of blur was given to both images together. A change in contrast or luminance was unable to counteract this loss and the deficit was not associated with convergence instability or accommodation changes.

Vergence movements required to bring two disparate parts of the visual field or stimuli into register for fusion are not affected by differences in the form, shape or luminance of the stereo stimuli (Westheimer and Mitchell, 1969; Mitchell, 1970).

Stereoacuity measured with classical stereoscopic stimuli is affected only if there are major modifications to the spatial frequency composition of the stimuli whereas random-dot stereograms do not appear to be similarly affected by changes to one stereo field. However, depth is disrupted in these displays when some of the elements are complemented and Julesz (1971) designed a stereo test based on complemented stereograms as a diagnostic tool to investigate stereo-deficiencies.

8.4. Stereo-anomalous Observers.

Some observers of random-dot stereograms are unable to appreciate depth even though they have had no history of strabismus. Julesz (1971) states:

> "There is a remote possibility that their inadequate stereoscopic performance is the result of poor viewing habits. Perhaps they learned to rely too much on monocular depth cues and possess a very dominant eye."
>
> (Julesz, 1971, p 270)

A test was designed to quantify this deficiency. A series of stereograms were presented that had 10-60% of the dots in the matrix complemented, that is, white elements or dots were changed to black and vice versa. This procedure makes the task of fusion and depth perception more difficult. The stereograms are briefly displayed and subjects are asked to register if depth is present. Subjects are classified on the percentage of depth detections made with repeated presentations of each type of complemented stereogram. With a high % of dots complemented, fusion and depth is difficult and subjects who consistently report depth in these displays are classed as having good stereopsis. However, no explanation is offered as to the nature of the deficiency of the subjects that are unable to detect depth and fuse displays that have been complemented, or as to the nature of the diagnosis.

In a series of psychophysical studies, Richards (1970, 1971) has reported that some stereoscopic abnormalities are related to specific disparities. For some individuals convergent disparities could be detected and discriminated, but depth with divergent displays was not appreciated. Richards suggested that this loss may be associated with a particular deficiency of one of three possible pools of disparity detectors. These deficits were not accompanied by fusional vergence abnormalities. However, Jones (1973) reported that some subjects with good stereoacuity showed abnormal vergence movements for large disparate stimuli.

No study has utilised response times to see depth in random-dot displays with modifications to one or both stereo fields as a tool for investigating asymmetries in binocular vision. The following section outlines the use of response latencies to see depth as a procedure for investigating stereoscopic vision and as a tool for measuring ocular asymmetries.

8.5. Stereoscopic Latencies to See Depth in Random-dot Stereograms

The time taken to fuse random-dot stereograms and see the depth effect is usually longer than the time required to see depth with classical stimuli (Julesz, 1971, 1978). The greater time required may reflect the longer processing time required by the stereopsis system to fuse these inherently ambiguous random-dot displays. Depth can be seen in briefly presented random-dot stereograms if the disparity range is small ie. falling within the fusional limits (Mayhew and Frisby, 1979). With disparities outside this range (13' of arc) exposure times have to be increased to allow fusional vergence movements to bring the displays into register and these are taken to be 160 ms (Westheimer and Mitchell, 1969).

With successive viewing of random-dot stereograms with large disparities the time taken to see the depth effect often decreases. Julesz (1971, p 217) proposed that there was a learning effect taking place that was dependent on eye movement strategies. An efficient sequence of eye movements is believed to be required for a particular level of disparity and this is transferred to the next stereogram viewed. Classical stereograms provide monocular visible features to guide eye movements for appropriate registration of the two images. With random-dot stereograms no such cues are available and several vergence movements may be made prior to fusion. Conjugate eye-movements may also be important for fusion of random-dot stereograms. The surface in depth to which the vergence movements must be directed cannot be identified in stereograms of this sort until vergence and fusion have occurred. Saccades may occur across the display to search for disparate areas and also after initial convergence, saccades may occur to scan the form in depth in order to establish its clarity. If the disparity is large, these saccades may destroy fusion if rapid in execution (Fender and Julesz, 1967) or vergence errors may occur during the execution of the saccades and result in the loss of fusion or partial fusion. There are no features available to correct or reduce the vergence errors in these random-dot displays.

Response times to see depth in random-dot stereograms are reduced if monocular features are added to the stereograms. It has been suggested that these features guide appropriate fusional vergence movements to the plane of disparity (Saye and Frisby, 1975). Such cues do not reduce stereoscopic latencies for small disparate displays which in their study had 5' of arc disparity. Fusion of these small disparate displays do not require vergence movements therefore it would not be expected that monocular features would reduce stereoscopic latencies.

It would be expected that response latencies to see depth with large disparity stereograms would be greater than for small disparate displays. Also, Saye (1976) could find no evidence of the learning effect (ie. the reduction in latencies) transferring from a stereogram with monocular features to a stereogram without them suggesting that "on-line" control of the vergence system is required for efficient fusion of the display. Julesz's (1971) hypothesis is not supported by these findings. It appears that some eye movement learning may take place but not necessarily the sequence of appropriate vergence shifts required to fuse large disparate displays.

Monocular cues do appear to be important for vergence control. Using direct eye movement recording techniques, the addition of monocular features resulted in faster vergence velocities relative to those in response to stereograms without these features (Mowforth, Mayhew and Frisby, 1981).

Stereoscopic latencies can be used to measure the effects of selective modification of the stereo fields with the aim of developing a measure of ocular asymmetry. The rationale used in developing this measure is outlined below.

8.6. Rationale of Selective Attenuation of the Displays to the Two Eyes

In the series of experiments to be reported in Part III, selective attenuation of the displays is used to derive a measure of ocular asymmetry. Attenuating one eye has frequently been used as a therapeutic technique for clinical eye defects. Visual acuity is known to increase in the amblyopic eye if a neutral density filter is placed over the non-amblyopic eye. It is assumed that the filter reduces the amount of interocular suppression or inhibition in the amblyopic eye (Von Noorden and Leffler, 1966).

Several studies were reviewed in the Introduction that used differential levels of attenuation of one or other eye to obtain equivalent monocular performance levels (Humphiss, 1969; Francis and Harwood, 1951). Differential response times between the eyes on visual tasks have also been reported and used to derive a measure of ocular asymmetry (Poffenberger, 1912; Minucci and Connors, 1972; Money, 1972; Perry and Childers, 1972).

In these studies stereoscopic latencies to make a depth discrimination were recorded using random-dot stereograms with two disparate square areas. Selective attenuation was applied to either both or neither displays, or to the left display alone or the right display alone. Any differential in the latencies for the two latter, unequal luminance conditions was used as a measure of ocular asymmetry. The condition of attenuation resulting in the faster response time was assumed to reflect the direction of the asymmetry towards that eye. Attenuation of the other eye would be expected to produce a longer response time thereby increasing the "imbalance" or asymmetry between the eyes.

Two levels of disparity were used for the stimuli in these experiments, i) small disparity values, that are assumed to require no vergence eye movements and ii) large disparity values that require vergence eye movements for fusion and depth. If asymmetries between the eyes involve an eye movement component an interaction would be expected between the ocular asymmetry and the two disparity values. A measure of asymmetry would be expected from the results from the large disparate displays but not from the small disparate displays.

8.7. An Outline of the Chapters in Part III

Chapter 9 is divided into two sections, Part A and Part B. Two experiments are reported in Part A using the depth discrimination procedure with random-dot stereograms, one with large disparities, 24/28' of arc and one with small disparities, 12/16' of arc. A measure of ocular asymmetry was derived from the mean stereoscopic latencies for the two unequal luminance conditions.

The experiments reported in Part B were designed to replicate the previous studies on binocular rivalry and depth discrimination with a group of seven new subjects. The experiments were designed to test if the range of rivalry measures of ocular asymmetry would be greater with a group of subjects with no experience of rivalry recording and to replicate the relationship between depth discrimination and rivalry measures of asymmetry with a group of subjects with ocular asymmetries towards the right eye (measured by rivalry).

In chapter 10, again divided into two parts, experiments are reported using the depth discrimination procedure with selective attenuation of the displays to the two eyes but with partially complemented random-dot stereograms (referred to as "scrambled" in this study). In Part B of this chapter an experiment was designed as a control for strategies that may be used during viewing of the random-dot displays. Stereograms with small and large disparities, "scrambled" and "unscrambled" were presented in a random sequence. Twenty subjects participated in this experiment in which the displays were presented randomly in one experimental session. All the above experiments were carried out independently, each experiment having a constant disparity baseline value. The disparity values for the small disparate displays were reduced to 8 and 12' of arc and presented randomly in one experimental session.

The experiment reported in Chapter 11 was also a control experiment for the small disparate displays used in the previous studies. This was designed to test if the ocular asymmetry measures were related to eye movements (ie for large disparate displays only) or if some other factor(s) was involved. Small disparity stereograms with disparate areas of 8/12' of arc were briefly presented at exposure durations below the 160 msec latency believed to be characteristic of vergence movements.

CHAPTER 9

PART A: Depth Discriminations using Small and Large Disparity Stereograms with Selective Attenuation of the Left and Right Eye Images.

9.1. Introduction

Two experiments are reported in this chapter involving depth discriminations as a function of selective attenuation of the images to the two eyes to derive a measure of ocular asymmetry. The experiments were designed to investigate the following hypotheses:

1). That latencies to make a depth discrimination for the conditions of unequal luminance to the two eyes would be longer than those for the two conditions of equal luminance.

2). That latencies for the large disparity displays would be longer than those with small disparity values, reflecting the involvement of the vergence system (Saye and Frisby, 1975).

3). That latencies for the two unequal luminance conditions, the right display attenuated, the left display attenuated are not equivalent for any given subject and form the basis for an ocular asymmetry measure.

And in addition,

4). That there would be an interaction of the two unequal luminance conditions with the two disparity levels ie. the small and large disparity stereograms.

5). A measure of ocular asymmetry based on the latencies for the two unequal luminance conditions would indicate direction and degree of this asymmetry.

6). The comparison of this measure of asymmetry with the binocular rivalry measures of ocular asymmetry and the conventional eye dominance test, sighting dominance (see Part I, Chapter 7).

9.2. Method

9.2.1. Subjects

Eight subjects from the previous experiment participated. They had good stereoscopic vision as tested by their ability to identify the different shapes in depth in Julesz random-dot stereograms (reproduced in slide form from Julesz, 1971, Fig 8.1-1, p 272).

9.2.2. Apparatus

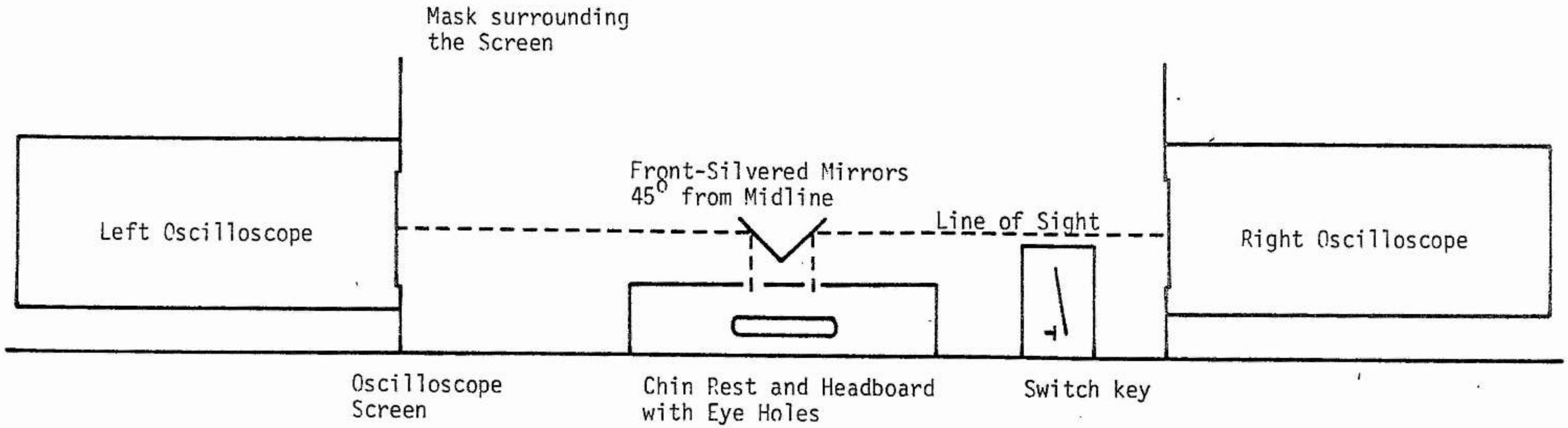
Fig 9.1 shows the plan of the modified stereoscope arrangement. The stereograms were generated on-line by the computer and displayed on the Tektronix 604 oscilloscopes in a modified stereoscope arrangement. The frame of the CRT screens of each scope was masked to give a viewing area of 10° X 13.5° showing the dot display and adjacent surround. The stereo fields were binocularly aligned by two front-silvered mirrors set at 45° from the midline in order to appear superimposed. The displays were positioned 57 cms from the observer who viewed the displays through eye holes with a headboard and chin rest. A dim light positioned behind the mirrors illuminated the room. A switch key was positioned to the right of the subject. A fixation point was provided on each oscilloscope screen that appeared centred for each half display. An additional voltage was supplied to the z-signals of each scope to modulate the displays. This was set to produce a 1 log unit attenuation of the display. The z-signals for each scope were independent and controlled by the experimenter. When the z-signal was modulated the luminance of the display was attenuated and not the surround.

9.2.3. The Stereograms

The random-dot stereograms were generated on-line by the Nova 1220 computer. Each stereo field was composed of 64 x 64 dots and subtended a visual angle of 4° x 4°. The distance between the dots was 4' of arc. The space-average luminance was 6.00 cdm-2 set against the surround of the screen with a space-average luminance of 0.87 cdm-2. The random-dot matrix was different for each stereogram displayed.

Each stereogram had two disparate square areas one above and one below the fixation dot. Each subtended a visual angle of 1° 8' x 1° 8'. The disparity values were always crossed and the disparity level was set at

Fig 9.1 Plan View of Apparatus used to Display Random-dot Stereograms in the Depth Discrimination Experiment.



the beginning of the experiment by stating the number of dots or elements the square areas were to be shifted relative to the surround. However, the two square areas had a constant disparity difference of 4' of arc. The square with the greater disparity was randomly assigned to either the top or bottom square throughout the trials. The disparity of the square areas for the first experimental session were 24' and 28' of arc. For the second experimental session the disparities were 12' and 16' of arc. Three practice trials were given before the start of the experimental sessions, the disparities in these stereograms were 16' and 20' of arc.

9.2.4. Procedure

Subjects were asked to fixate the central fixation dot at the beginning of each trial. When the stereograms were on the screens subjects were asked to keep their eyes on or around the fixation point.

The subjects task was to discriminate which of the two squares in depth stood out further from the surround. The switch key was to be pressed as soon as they could make this judgement and to indicate to the experimenter if it was the "top" or "bottom" square. Subjects were asked to respond only if they were certain that they could discriminate the two areas at different depths.

When the switch key had been pressed the stereogram stayed on for a further 3 seconds to allow for further viewing of the fused display. If no response was made during the maximum presentation time of 30 seconds the stereograms were removed. The inter-trial interval was 18 seconds and the scopes were blank during this time.

It was emphasised to the subjects that depth may not appear immediately on viewing the stereograms and that they should keep trying to get the depth effect the whole time the displays were on the screens. If subjects could not discriminate a depth difference they were asked to indicate if any depth in the displays was present. They were told that some displays may appear dimmer than others.

Three practice stereograms were presented with no attenuation of either display before the beginning of the experimental session. There were two experimental sessions 1) the disparities were 24/28' of arc and 2) the disparities were 12/16' of arc. There was a two month interval between the administration of the two experimental sessions and subjects always participated in the large disparity experiment first (1). There were forty trials in each session, ten trials in each condition as shown below:

Condition 1: Neither display attenuated by 1 log unit
Condition 2: Both displays attenuated by 1 log unit
Condition 3: Left scope attenuated by 1 log unit
Condition 4: Right scope attenuated by 1 log unit

The attenuation was controlled by the experimenter. The four conditions of selective attenuation were randomly assigned over the forty trials. Each subject received the same trial sequence.

9.3. Results

9.3.1. Stereoscopic Latencies for the Four Conditions of Selective Attenuation

The time taken to make a depth discrimination was recorded for each subject on-line by the computer. If no response was made during the 30 seconds the display was on the screens a latency of 30 seconds was substituted in the analysis. If incorrect judgements were made as to which square had the greater depth they were analysed as errors and in the response time analysis the mean reaction time for that condition of selective attenuation for that subject was substituted. The results from the two experimental sessions were analysed separately.

(1) It is possible that practice effects may occur that could transfer from the experimental session with large disparities to the ones with small disparities. However, the interval between the two was two months and if any practice effects did occur they are unlikely to interact with the ocular asymmetry effects.

i) Experiment 1: 24/28' of arc Depth Discrimination

Table 9.1 shows the mean stereoscopic latencies for each subject under the four experimental conditions. There is a wide variation between subjects in the mean latencies to make a depth judgement. The response latencies for the two unequal attenuated conditions (the two columns on the far right) are consistently longer overall than those for the two equal luminance conditions.

An analysis of variance was carried out on the response time data. The factors were conditions (4 levels) and trials (10 trial presentations). (See Appendix E, for summary table and comparison between the means). The response times under the four experimental conditions were significantly different ($F = 4.58$, df 3,21, $p<0.02$). A planned comparison between the means showed a significant difference between the two equal luminance conditions (1 and 2) and the two unequal luminance conditions (3 and 4) ($F = 12.727$ df 1,21, $p<0.005$) the mean stereoscopic latencies were 4.54 and 9.23 seconds respectively. No other factor or interaction reached significance. It can be seen that the stereoscopic latencies for the unequal luminance conditions in Table 9.1 are not equivalent, for example subject SK shows a longer response time to discriminate the depth planes with the right display attenuated relative to the response times for the left display attenuated. Subject GM shows an asymmetry in the opposite direction.

ii) Experiment 1: 12/16' of arc Depth Discrimination

Table 9.2 shows the stereoscopic latencies for the same group of subjects under the four experimental conditions for the small disparity stereograms. The latencies are overall shorter than for the large disparate stereograms and there is little difference in the response times for the conditions of selective attenuation. The results of the analysis of variance (carried out as above) showed no significant difference in stereopsis latencies between the attenuation conditions ($F = 2.404$, df3,21, not significant). The mean response time averaged over conditions 1 and 2 is 2.69 seconds and 2.49 seconds for the average of conditions 3 and 4. It can be seen from Table 9.2 that there are asymmetries in the stereopsis latencies for the two unequal luminance conditions especially for subjects SK and GM both of whom have overall longer response times.

Table 9.1 Mean Stereoscopic Latencies (seconds) and standard deviations (SD) for each Subject to Make a Depth Judgement between Two Squares (24'/28' of arc) under Four Conditions of Selective Attenuation.

	Attenuation Conditions							
	1 Neither Display	SD	2 Both Dsplays	SD	3 Left Display	SD	4 Right Display	SD
Subjects:								
GR	5.99	3.70	5.98	2.50	14.60	9.55	13.59	9.71
SW	0.90	0.07	2.41	1.26	1.47	1.06	2.71	1.31
SK	7.41	3.29	8.19	2.83	7.21	1.85	17 36	10.79
SM	2.40	1.72	2.65	0.75	3.67	2.42	6.84	6.23
GM	2.64	0.92	9.20	7.35	22.65	10.28	12.56	8.82
ID	2.72	2.23	3.44	3.69	3.87	3.88	3.59	2.11
AH	5.50	1.80	9.83	5.60	20.29	9.52	13.54	6.94
CB	1.44	0.43	1.93	0.94	1.70	0.60	2.00	0.96
Mean	3.63		5.45		9.43		9.02	

$F\ (3,21)\ 0.02 = 4.5803,\ p < 0.02$

Table 9.2 Mean Stereoscopic Latencies (seconds) and standard deviations (SD) for Each Subject to Make a Depth Judgement between Two Squares (12'/16' of arc) under the Four Conditions of Selective Attenuation.

	Attenuation Conditions							
	1 Neither Display		2 Both Displays		3 Left Display		4 Right display	
		SD		SD		SD		SD
Subjects:								
GR	1.29	0.37	1.37	0.48	1.45	0.67	1.38	0.26
SW	0.98	0.19	1.34	0.51	1.31	0.61	1.02	0.10
SK	7.93	2.60	12.40	7.11	9.26	3.60	7.19	1.80
SM	1.65	0.68	1.49	0.49	1.73	0.44	1.73	0.39
GM	1.90	0.45	4.85	1.54	4.39	1.76	2.26	1.18
ID	0.51	0.17	0.62	0.19	0.65	0.23	0.53	0.19
AH	2.11	0.47	2.51	0.81	2.35	0.56	2.40	0.59
CB	1.10	0.13	1.03	0.20	1.15	0.34	1.08	0.18
Mean	2.18		3.20		2.78		2.20	

$F\ (3.21) = 2.404$, not significant.

9.3.2. Comparison of the Small (12/16') and Large (24/28') Disparity Stereograms

Fig 9.2 shows the response latencies for each subject for both experiments. It can be seen that the stereoscopic latencies are shorter with small disparity stereograms for all subjects except SK. More important is the variability in the latencies for the large disparate displays with the conditions of selective attenuation.

9.3.3. Measures of Ocular Asymmetry

A measure of ocular asymmetry was derived from the mean stereoscopic latencies for the left and right attenuation conditions (3 and 4) for each subject using the formula;

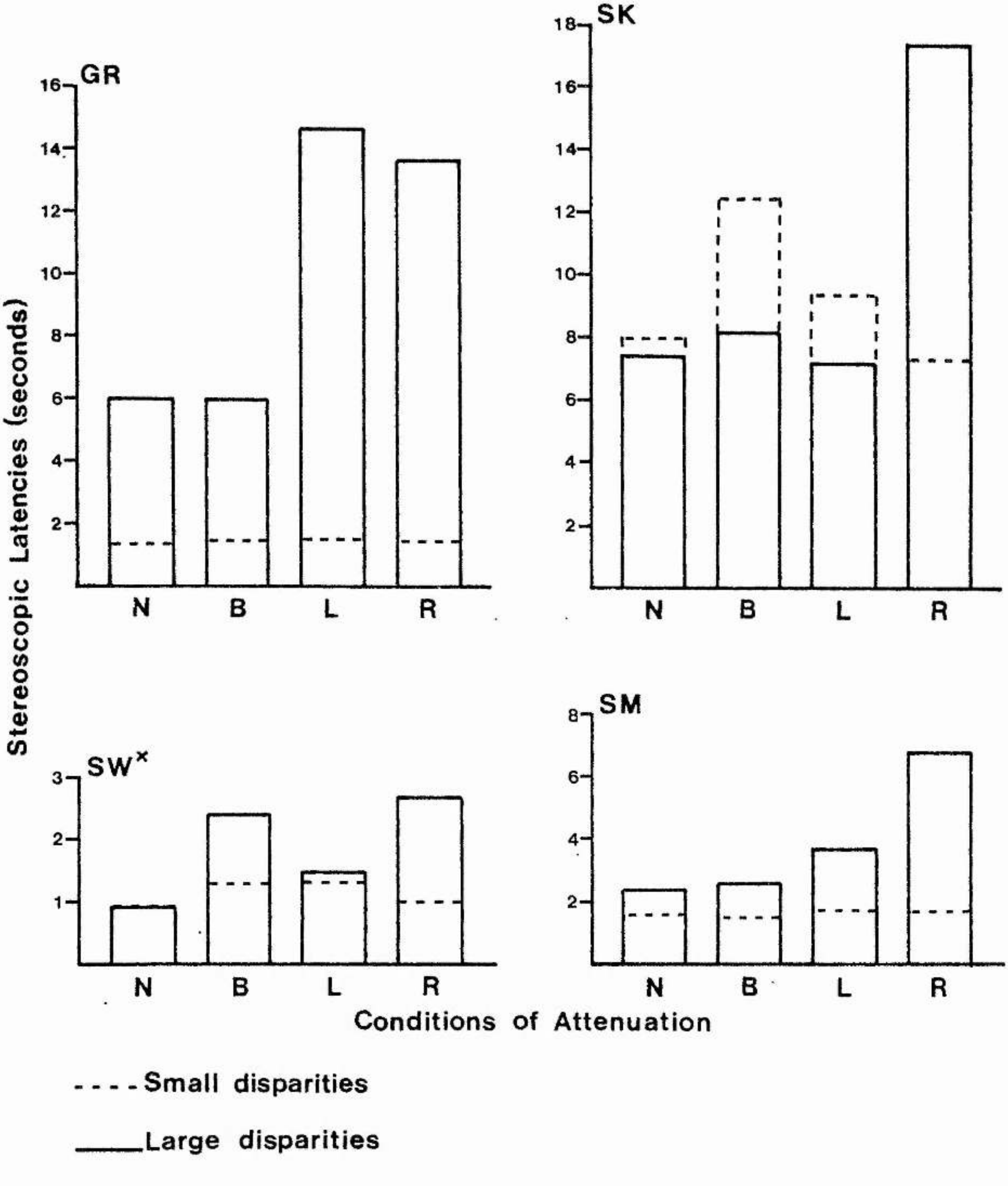
$$\text{Ocular Asymmetry score} = \frac{\text{RESL} - \text{LESL}}{\text{RESL} + \text{LESL}}$$

RESL = mean stereoscopic latency for attenuation of the display to the right eye.

LESL = mean stereoscopic latency for attenuation of the display to the left eye.

This is an equivalent measure to that used in the binocular rivalry experiments given the rationale outlined on p 115. The shorter response latency of the two conditions represents the attenuation of the dominant eye therefore, a positive value reflects an asymmetry towards the left eye and a negative value reflects an asymmetry towards the right eye. Table 9.3 below shows the direction and the degree of asymmetry for each subject using the above formula.

Fig 9.2 Histograms of the Mean Stereoscopic Latencies (seconds) to Make a Depth Judgement with Small and Large Disparity Stereograms for Each Subject.

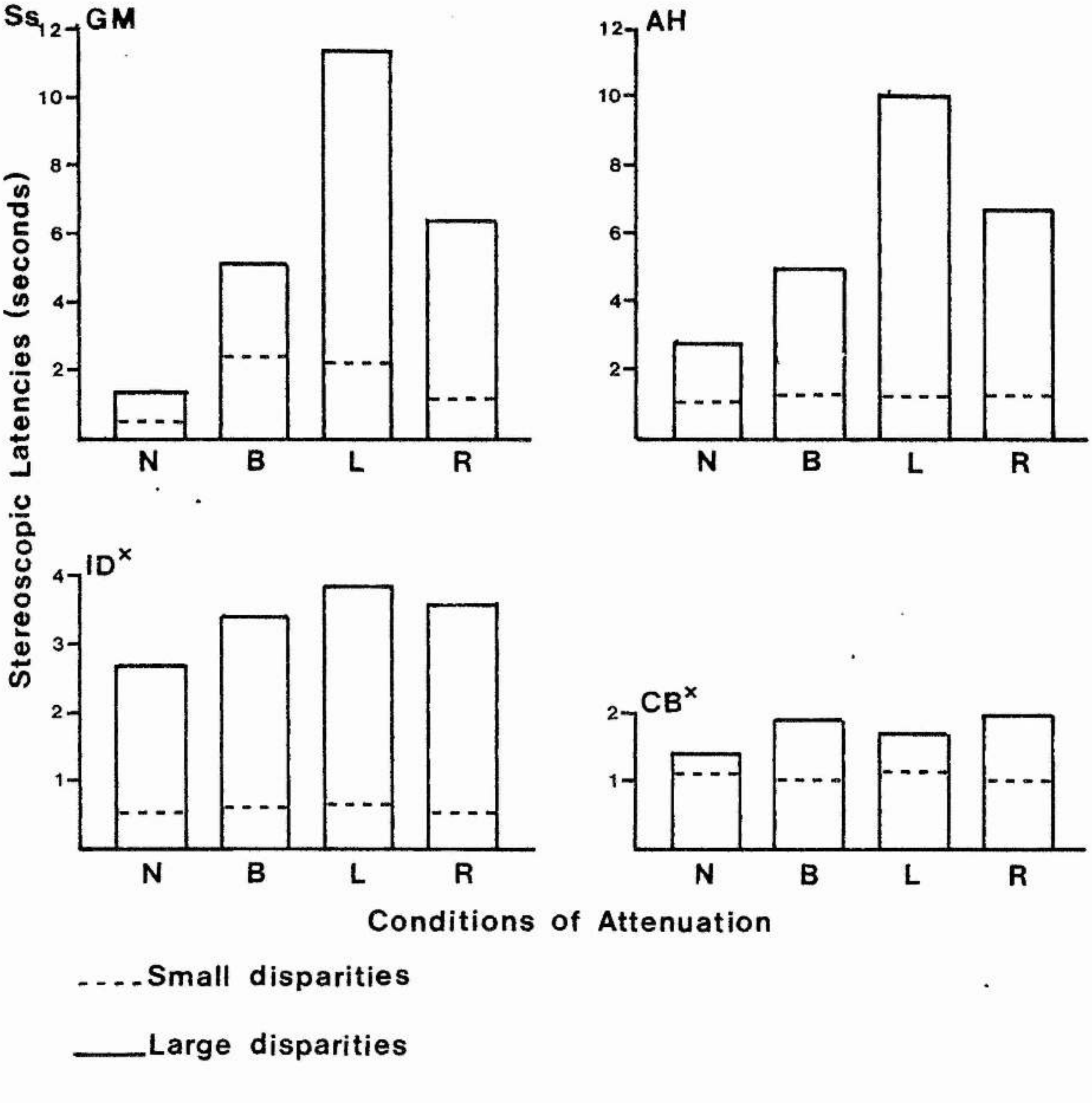


N = Neither display attenuated. L = Left display attenuated.

B = Both displays attenuated. R = Right display attenuated.

× = Increased scale.

(continued).



N = Neither display attenuated. L = Left display attenuated.
B = Both displays attenuated. R = Right display attenuated.

Table 9.3 Ocular Asymmetry Scores

Disparity values:	24/28' of arc	12/16' of arc
Subjects:		
GR	-0.036	-0.07
SW	0.30	-0.12
SK	0.41	-0.13
SM	0.30	0.001
GM	-0.29	-0.32
ID	-0.04	-0.10
AH	-0.20	0.01
CB	0.08	-0.03

The asymmetry scores for the small disparity depth discrimination experiment for nearly all subjects are relatively small compared to the scores derived from the large disparity stereograms (ie. ignoring the direction of asymmetry). The mean degree of asymmetry is 0.10 and 0.21 for the small and large disparity stereograms respectively. Subjects GM and SK with the overall longer stereoscopic latencies for the small disparity experiment have the greater asymmetry scores.

9.3.4. Frequency of Incorrect Judgements and Failures to Discriminate Depth

i) Experiment 1: 24/28' of arc Depth Discrimination

Fifteen incorrect judgements (out of a total of 320 trials) were made, seven trials with the right display attenuated, eight with the left display attenuated.

On a further fifteen trials no depth difference or any depth effect could be discriminated during the 30 seconds of viewing. Of these fifteen trials, twelve occurred with unequal attenuation of the displays and three with equal attenuation of the displays. Of the unequal conditions, nine occurred with the dominant eye attenuated and three with the non-dominant eye attenuated as defined by the scores above. For each of the nine trials the squares were reported as being seen in depth above the surround although a difference of 4' of arc could not be distinguished. The remaining three trials were for the non-dominant eye attenuated condition and no depth in the displays was reported.

ii) Experiment 2: 12/16' of arc Depth Discrimination

Two subjects made incorrect judgements on a total of five trials with both displays of equal luminance and one trial for each of the unequal luminance conditions. Depth could be discriminated on every trial.

9.3.5. The Depth Discrimination Measures and the Binocular Rivalry Measures of Ocular Asymmetry

The measures of ocular asymmetry derived from the above experiment using selective attenuation of the two stereo displays for eight subjects were compared with their measures of ocular asymmetry derived from the real image binocular rivalry experiment using the four response category procedure (see Chapter 6, p 89)(2).

The correlation coefficient for the binocular rivalry measures with the depth discrimination measures for the large disparate displays is r = 0.65 (n=8) which is significant at the 5% level (one tailed test). Fig 9.3 shows the scatterplot of these scores and the linear regression line with equation Y = 0.06 + 1.91X. The depth discrimination measures for the small disparate displays that were based on the two unequal luminance conditions (these were not significantly different from the equal luminance conditions) do not show a significant correlation with the same binocular rivalry measures as above. The correlation coefficient is r = 0.42 (not significant).

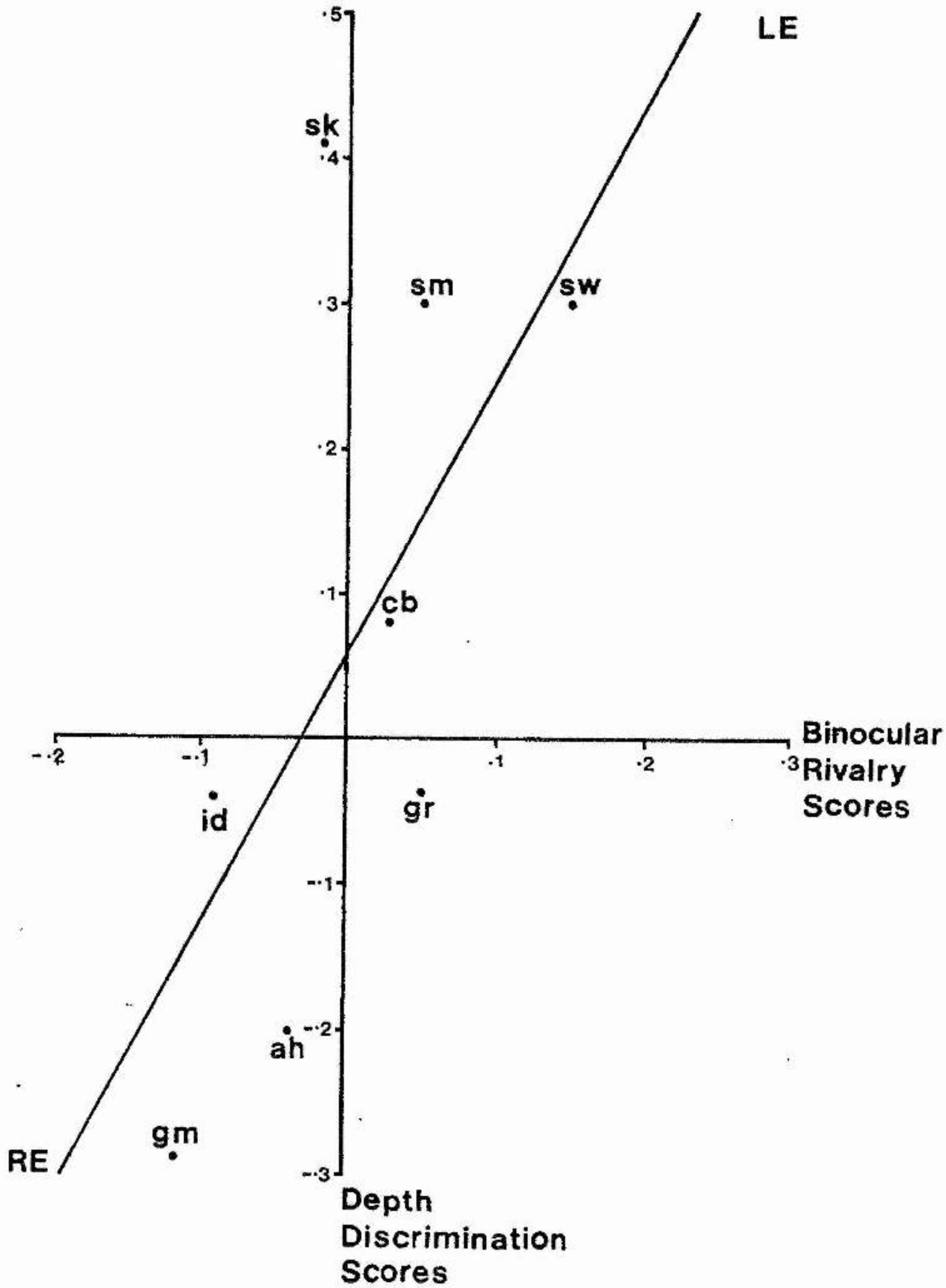
(2)The afterimage binocular rivalry measures of asymmetry (chapter 4) correlated non-significantly with 1) the large disparity depth discrimination measures, r = 0.57, and 2) with the small disparity depth discrimination measures, r = 0.62. However, binocular rivalry with afterimages was not measured using the four response category procedure which was found to shift the direction of the real image rivalry asymmetry scores and make them smaller. Therefore, these correlations should be interpreted with caution. This does not however weaken the finding of the close relationship between real image and afterimage rivalry based on the two response procedure.

9.4. Discussion

i) Stereoscopic Latencies for the Small and Large Disparity Stereograms

The mean latency for the small disparity stereograms (12/16') over all conditions was 2.64 seconds compared to the longer mean latency of 6.87 seconds for the large disparity stereograms. Saye and Frisby (1975) reported a similar difference in response times to see depth for

Fig 9.3 Ocular Asymmetry Scores for Eight Subjects derived from the Binocular Rivalry Experiment with Real Images and the Depth Discrimination Experiment with Large Disparities (24'/28' of arc).



r = 0.65, $p < 0.05$ (one-tailed test).

random-dot stereograms of 5' and 1° 17' of arc disparity.

Stereoscopic latencies for the small disparities in this study and the smaller ones in the Saye and Frisby study were in the order of seconds. These long latencies to see the depth effect may partly reflect the inherent ambiguity of the stimuli used and the time taken for the stereopsis mechanism to process binocular fusion and depth. Random-dot stereograms have many possible theoretical fusions although only one fusional solution is the correct one to achieve the stereoscopic percept. This takes longer to achieve with random-dot displays than with the classical stereograms.

However, the small disparate displays in this experiment were 12 and 16' of arc. These disparity levels may also require vergence shifts prior to fusion although not as large as those required for the 24' and 28' of arc disparity stereograms. Fender and Julesz's (1967) data indicate that Panum's fusional area for random-dot stereograms is 6' of arc and any disparity greater than this requires vergence shifts. However, Mayhew and Frisby (1979) reported that subjects could discriminate depth in disparate unfiltered random-dot stereograms of 13' of arc in 60 ms which is shorter than the latencies required for vergence eye movements which are usually taken to be 160 msecs (Westheimer and Mitchell, 1969). In a free-viewing situation as in these experiments, and for many "naive" subjects slight vergence shifts may still occur for fusion of both the 12' and 16' of arc disparate squares.

Greater variance in the latencies was found for the large disparity displays compared to the small disparities. Vergence movements are required to bring the two stereo fields into register. These take time to initiate and execute. There is no information for guidance of these vergence movements. This may account for some of the variability, ie. on some trials the vergence movements may be appropriate to attain fusion and depth resulting in short stereoscopic latencies and the long stereoscopic latencies on other trials may reflect inappropriate vergence movements.

The vergence hypothesis is partially supported; stereopsis latencies were longer for the large disparate displays reflecting involvement of the vergence system. When the subject fixates the central fixation spot (zero disparity) when the stereo display is on the screen, the background or surround of the disparate areas may be fused as these fall on corresponding visual fields of the two retinae. The disparate squares 24' and 28' of arc fall outside the disparity limits for binocular fusion and a vergence shift(s) will be required to bring these areas within this range. The work of Fender and Julesz (1967) showed that once fusion has been established the two displays can undergo 2° of misalignment before fusion is lost (this has been termed the hysteresis effect). Thus fusion of the background dots are not destroyed by the vergence shift(s) required to achieve fusion and depth of the disparate areas.

There was no evidence of learning to fuse the random-dot stereograms as realised by a decrease in stereoscopic latencies over successive trials. Julesz (1971) believes that learning occurs in random-dot stereograms by an efficient sequence of fusional eye movements. He states;

> "The learning task is similar to exploring a maze. At each strategic junction one must learn whether a nasal or temporalward shift should be made. The correct sequence of these forks and the direction is apparently learned unconciously and rapidly."
>
> (Julesz,1971, p 217)

The random-dot displays contain no "on-line" guidance for the appropriate vergence movements and it appears that some form of "on-line" guidance is required for this learning of the fusion eye movement strategies to occur. Saye et al (1975) found that the "on-line" guidance in the form of a monocular feature overlaying the disparate area resulted in a learning effect but that this did not transfer to stereograms that contained no monocular visible features. Therefore, given the stereograms used in this study a reduction in response times over trials would not be expected. However, practice at fusing random-dot stereograms without monocularly visible features may be responsible for the individual differences found in the overall latencies. Subject SW is well practiced at viewing these displays and has short latencies whereas subject SK has long latencies and has had less practice. The instructions prior to the experiment requested subjects to fixate the central spot and if subject SK maintained this fixation for some time before relaxing fixation and allowing convergence and divergence to occur latencies would be lengthened. More experienced subjects may have learnt that fusional eye movements are necessary for fusion although given the above results (Saye and Frisby, 1975) it is not necessarily the sequence of vergence shifts required for fusions of large disparate displays that is learnt.

9.4.2. Unequal and Equal Luminance of the Displays

Subjects reported that they were unaware of which display was attenuated and only on some trials did the display appear "brighter". It has been reported that individuals with good stereopsis are unable to distinguish which eye has been stimulated (Blake and Cormack, 1979a; Templeton and Green, 1968).

The first hypothesis was confirmed for only the large disparity displays. With the large disparity displays latencies were increased with unequal luminance of the stereofields relative to equal luminance. This pattern did not occur significantly with the small disparate displays. There has been no study that has reported a similar finding of unequal attenuation of stereoscopic displays on response times. A 1.6 log unit difference in luminance for large disparate bars has been reported to have no effect on the initiation of vergence movements but the velocity of the vergence movements were decreased relative to equal luminance of the displays (Mitchell, 1970). Vergence movements in the Mitchell (1970) study were not reported as being asymmetrical for displays of unequal luminance. No explanation was offered to explain this decrease in velocity.

The findings in this study suggest that unequal luminance of the stereo displays has an effect on response times only if vergence movements are involved. Vergence movements are continually monitored and disparity information is used to initiate and guide these movements to achieve fusion (Rashbass and Westheimer, 1961). If there is a delay in one signal relative to the other and a comparison of the two signals is required at the binocular site that subserves the vergence system, then vergence initiation may be delayed. Therefore, it is assumed that it is the difference in the stereoscopic latencies for the two conditions of unequal attenuation that reflect asymmetries in speed of processing. The overall delay in latencies for the two unequal conditions above that of the both display attenuated condition is assumed to reflect the delay of the signals arriving at the binocular site that are required for continous monitoring of information for vergence control, the delay being imposed by the conditions of unequal attenuation of the displays.

It is possible that a one log unit reduction of one display imposes a delay in the signal arriving at the binocular site. This delay may increase the time required for registering the disparity in the display and for a change in vergence angle required to eliminate the disparity. Evidence for binocular cooperation in vergence comes from the findings that the average error between the position of the two eyes is computed and may be used as the basis for control of vergence movements (Alpern, 1969; Westheimer and Mitchell, 1956).

Smooth pursuit eye movements have been reported in response to depth and motion in dynamic visual noise where one eye is filtered (Le Leguire, 1981). The velocity of the movements were an inverse function of the density of the filter. Movements decreased in velocity with a 0.5 to a 1.0 log unit attenuation. A similar arguement to the above may also account for these results.

Further evidence in support of an eye movement hypothesis involving the fusional vergence system comes from some earlier pilot work. A pilot experiment was carried out with ten subjects using a similar procedure to the above except; 1) the two disparate square areas were to the right and left of the fixation point, 2) the attenuation was carried out using one log unit neutral density filters placed in front of the eyes and 3) the disparity values were 16 and 20' of arc. The disparities used in this pilot study were intermediate of the two disparity values used for the small and large disparity experiments. If unequal attenuation induces a delay in the signals arriving at the binocular centre that subserves the vergence system then the more vergence shifts or the greater the vergence shifts required to fuse the displays the longer the latencies would be in relation to displays requiring fewer shifts. The mean latencies to make a depth judgement were 3.4 seconds for the two equal luminance conditions and 4.25 seconds for the two unequal luminance conditions. A comparison of these mean stereoscopic latencies above with those in Tables 9.1, 9.2 shows that they lie approximately midway between the stereoscopic latencies for the small and large disparate displays. This gives further support to the vergence latency hypothesis to explain the response times to make a depth judgement under the unequal luminance conditions.

Given the above eye movement hypothesis response times would not be expected to be affected by unequal luminance of stereo fields with small disparate displays that do not require vergence movements prior to fusion. It has been suggested that given the long latencies reported for the small disparate displays vergence shifts may occur with disparities of 12 and 16' arc. The results show the stereoscopic latencies are not affected by conditions of selective attenuation. It may be that the vergence shifts required for fusion are so small that unequal luminance does not markedly influence the velocity and speed of execution and hence do not affect the response times. Alternatively, depth and fusion of the small disparity stereograms may be a relatively easy fusional task resulting in short latencies that mask any effects of selective attenuation, ie. "floor" effects may be operating.

9.4.3. Measures of Ocular Asymmetry

Measures of ocular asymmetry were derived from the mean stereopsis latencies for the two conditions of unequal attenuation. The unequal luminance condition that resulted in the faster response time was assumed to reflect a situation of attenuation of the "dominant" eye. The measures give both the direction and degree of this asymmetry. There was an interaction of these asymmetry measures with the level of disparity. It is the difference in response times for the two conditions of unequal attenuation which are important for measures of asymmetry. Asymmetry scores were reported for the large and small disparity experiments although for the latter the difference between the two unequal attenuated conditions was small and also neither differed significantly from the two equal luminance conditions. The mean degree of asymmetry was also smaller for the small disparity displays compared to those for the large disparate displays.

Several studies have reported an asymmetry measure based on the speed of processing of visual information, it being faster for the dominant eye

(Poffenberger, 1912; Money, 1972; Munucci and Connors, 1972; Perry and Childers, 1972). By attenuating the eye that processes signals faster it may be possible to reduce this differential in processing speed. Attenuation of input to the eye with the slower speed of processing will increase the differential as reflected in increased latencies. This differential in processing capacity may also reflect asymmetrical interocular suppression. The dominant eye may exert more inhibition or suppression on the input from the non-dominant eye,(cf. masking studies). Attenuation may reduce this asymmetrical suppression in a similar fashion as to that reported for amblyopes (Von Noorden and Leffler, 1966). If the non-dominant eye is attenuated, inhibition from the dominant eye may increase or have a greater influence on the non-dominant eyes visual processing capacity.

Given an inherent asymmetry in visual processing between the eyes for binocular information, it might be expected that attenuation of the "dominant" eye by 1 log unit would result in stereoscopic latencies faster than the conditions of neither display attenuated and both displays attenuated. It can be see from Fig 9.2 that only one subject shows this pattern (SK) for both small and large disparity displays. (It is assumed that attenuation of both displays will not lengthen response times markedly above those for the neither attenuated condition as inputs from both eyes would arrive at the binocular site at the same time, although with the former condition the signals may arrive overall slightly later). It is possible that the inherent differential in processing speeds or inhibitory interactions that has been hypothesised may be reduced by an attenuation of less than 1 log unit and using a one log unit reduction in luminance as in this study introduces a greater differential between the eyes.

The measures of ocular asymmetry were small (mean of 0.10) for the small disparity displays and these were not significantly different from the equal luminance conditions. This suggests that ocular asymmetries are associated with the vergence system only, ie. those required for fusion of the large disparity displays. Therefore, the differential in processing speed as argued above would apply to the vergence system. It is possible that vergence velocity is reduced with unequal attenuation of the stereo-fields and this is greater when one eye is attenuated relative to the other. However, it is not known why this asymmetry exists for the binocular system that subserves vergence. It may be i) a difference in processing speeds of the two inputs, ii) asymmetrical inhibitory interactions and/or iii) an imbalance in the "sensitivity" of the binocular units towards one eye. This does not necessarily imply that the vergence movements are asymmetrical, but rather that the binocular co-operation required for vergence control is possibly delayed by unequal luminance of the stereo-displays.

It is interesting to note that for 12 out of the 15 trials in the large disparity experiment when a depth difference was not reported, the display to the dominant eye was attenuated. This suggests that appropriate vergence movements had occurred but that a 4' of arc difference between the two disparate areas could not be discriminated. However, this represents only 3.75% of the total trials and given that 30 seconds were allowed for fusion may reflect inappropriate fusion of the displays. If rapid saccadic movements are made across the displays fusion will be lost (Fender and Julesz, 1967). It is possible that at the end of 30 seconds only partial fusion may have been attained. Some elements would be fused and appear in different depth planes, giving the impression of "areas" in depth. Subjects were not questioned on these occasions as to the clarity of the depth effect they saw. A difference in these reports of "no depth difference" between the dominant and non-dominant eye attenuation conditions would have been expected if the vergence movements in the former condition were faster.

9.4.4. Binocular Rivalry and Depth Discrimination Measures of Ocular Asymmetry

A significant relationship was found between the depth discrimination measures of ocular asymmetry and the binocular rivalry measures of ocular asymmetry. This was found for the large disparity stereogram experiment only. This result demonstrates that measures of ocular asymmetry using a binocular viewing paradigm involving a co-operative process of depth discrimination with stereoscopic displays are similar to those derived from a competitive process as with binocular rivalry. Eye movements have been hypothesised to be involved in the measures of ocular asymmetry derived from both procedures.

The mean degree of asymmetry derived from the binocular rivalry procedure is small (0.067) relative to that derived from the large depth discrimination procedure (0.21). Small disparity depth discrimination measures of ocular asymmetry are small in degree (mean of 0.10) and do not relate to the binocular rivalry measures.

There does not appear to be a systematic relationship between asymmetry measures derived from the depth discrimination procedures and the sighting dominant eye. Only four subjects had a sighting dominant eye that was on the same side as the ocular asymmetry derived from the large depth discrimination experiment and the same number for the small depth discrimination experiment (7 subjects had a sighting dominant eye).

CHAPTER 9 continued.

PART B: A Replication Using a Group of Subjects with Right Ocular Asymmetries.

9.5.1. Introduction

A measure of ocular asymmetry has been reported in the previous section based on stereoscopic latencies to make a depth discrimination using selective attenuation of the stereo fields. The measure from the large disparity experiment correlated with another measure of ocular asymmetry derived from a binocular rivalry procedure with a correlation coefficient of 0.65 which was significant at the 5% level. However, the binocular rivalry measures of ocular asymmetry were small (0.067, if the direction of asymmetry is ignored) compared to the large disparity discrimination measures (0.21).

These subjects had already participated in previous experiments with binocular rivalry recording with real images using the two response procedure. Only two subjects had been classed as having a right ocular asymmetry. However, using a four response procedure asymmetry scores were reduced in degree and four subjects were classed as having an asymmetry towards the right eye. It was decided to repeat the binocular rivalry experiment with real images using a group of subjects that had had no previous experience of the two response procedure for recording rivalry and that were all classed as having a right ocular asymmetry score on the binocular rivalry task. It is possible that left eye dominant subjects as a group may be unusual in some way (Porac and Coren, 1976).

The experiments reported in this chapter are a replication of the binocular rivalry and the two depth discrimination experiments reported in Part A using a new group of subjects with right ocular asymmetries. The experiments were designed to replicate the previous findings for a group of subjects, relatively naive to rivalry recording.

9.6. Experiment 1: Binocular Rivalry Measures of Ocular Asymmetry

9.6.1. Method

9.6.2. Subjects

Seven subjects participated in the experiment, all drawn from the St Andrews student population. All subjects had good stereoscopic vision as tested by their ability to discriminate the shapes in the random-dot stereograms presented in Julesz's book and were presented in slide form (Julesz, 1971, p 272). All subjects participated in a preliminary trial of binocular rivalry using the same procedure as used in chapter 6 to determine the direction of asymmetry. Only subjects with a right asymmetry were chosen, the above seven subjects all had a rivalry right ocular asymmetry.

9.6.2. Apparatus

The apparatus was the same as that used for real image binocular rivalry viewing as reported in Chapter 6. Four categories of response were recorded as follows: responses for the images for the left and right eyes and a response for composites and "total disappearances".

9.6.4. Procedure

Two experimental sessions of rivalry with real images were given, six 90 second trials in each. The procedure was the same as that adopted in chapter 6.

9.7. Results

The mean overall durations each image or category was visible out of the 90 seconds of observation averaged over the 12 trials (two experimental sessions) are shown in Table 9.4. Seventy and half percent of the observation period is exclusively of whole rivalrous images, 27.6% is reported as composites. However it can be seen from Table 9.4 that subject FM has an overall mean duration of composites of 68 seconds which is exceptionally high in comparison to the other subjects in this group and in the other group (see chapter 6, p 87). If FM's data is excluded, 78.4% of the viewing time is exclusively of whole images and only 19.6% is of composites. This compares favourably with the previous groups results (24% composites).

Table 9.4 Mean Overall Durations (seconds) and standard deviations (SD) Each of the Four Response Categories is Reported to be Visible in the 90 second Inspection Period (1).

Image Visible:	LE	SD	RE	SD	COMPOSITES	SD	Tt.DISAPP.	SD
Subjects:								
FM	9.84	1.80	11.36	3.16	68.20	4.84	0.60	0.36
PC	30.47	2.37	40.05	3.06	18.83	3.36	0.70	0.45
RF	35.47	4.14	36.03	4.74	16.77	5.07	1.80	1.05
DM	21.86	5.93	33.81	3.62	31.21	8.43	3.20	2.33
SG	35.99	3.07	38.35	3.97	13.34	4.33	2.39	1.45
IW	30.82	4.36	44.51	5.73	11.89	4.33	2.84	2.32
PR	39.40	2.80	39.52	2.52	10.30	3.05	0.86	0.55
Mean	29.39		34.16		24.87		1.65	

LE - the duration the image to the left eye is visible.

RE - the duration the image to the right eye is visible.

Tt.DISAPP. - "total disappearances".

(1)The mean overall durations are the sum of each depression duration within the 90 second inspection period averaged over the 2, 90 second trials.

9.8. Measures of Ocular Asymmetry

Measures of ocular asymmetry were derived from the overall durations each image was visible for each 90 second trial (ie. 12) using the formula shown on page 66. The mean asymmetry scores and standard deviations are shown in Table 9.5.

Table 9.5 Ocular Asymmetry Scores

Subjects:	Mean asymmetry score	+-1SD
FM	-0.07	0.08
PC	-0.136	0.06
RF	-0.008	0.10
DM	-0.217	0.12
SG	-0.032	0.09
IW	-0.182	0.12
PR	-0.002	0.05

All subjects have right ocular asymmetries, the mean degree of asymmetry is 0.09.

9.9. Experiment 2: Depth Discrimination Measures of Ocular Asymmetry

The same seven subjects participated in the two depth discrimination experiments, one with small disparities and one with large disparities (see Part A). Subjects took part in the small disparity experiment first and in the large disparity experiment on the following day.

9.10. Method

The method was exactly the same as that described in Part A. Seven subjects from the above experiment participated and the small disparity displays were presented first.

9.11. Results

9.11.1. Stereoscopic Latencies for the Four Conditions of Selective Attenuation

i) 12/16' of arc Depth Discrimination

Table 9.6 shows the mean stereoscopic latencies for the seven subjects to make a 4' of arc discrimination in depth of two squares of 12 and 16' of arc under the four experimental conditions. The mean latency over all subjects and conditions is 3.24 seconds. The latencies were entered into an analysis of variance, the factors were; trials (10) and experimental conditions (4). There was no significant difference in stereoscopic latencies over the four conditions of selective attenuation ($F=2.30$, df 3, 18, not significant).

ii) 24/28' of arc Depth Discrimination

Table 9.7 shows the mean latencies to make a depth discrimination between two squares 24' and 28' of arc disparity under the four conditions of selective attenuation. The mean latency over all subjects and conditions is 8.15 seconds. The mean latencies for the conditions of equal luminance are shorter than those for the two unequal attenuated conditions and especially for the left display attenuated condition. An analysis of variance was carried out on the latencies as above. There was a significant difference in the stereopsis latencies over the conditions of selective attenuation ($F=8.68$, df 3, 18, $p<0.01$). A planned comparison between the means showed that the two conditions of unequal attenuation had longer latencies (mean of 10.8 seconds) than the equal luminance conditions (mean of 5.5 seconds, $F=12.72$, df 1, 18, $p<0.01$) and the left display attenuated condition had significantly longer latencies than the right ($F=10.90$, df 1, 18, $p<0.01$). (The summary tables for the two analyses are shown in Appendix E, together with the planned comparisons).

9.11.2. Measures of Ocular Asymmetry

The latencies for the two conditions of unequal attenuation are not equivalent for all the subjects as can be seen in Tables 9.6 and 9.7 and especially in the latter. These latencies were used to derive an asymmetry score using the formula shown in Part A, page 126.

Table 9.6 Mean Stereoscopic Latencies (seconds) and standard deviations (SD) for Each Subject to Make a Depth Judgement between Two Squares (12'/16' of arc) under Four Conditions of Selective Attenuation.

	Attenuation Conditions							
	Neither Display		Both Displays		Left Display		Right Display	
		SD		SD		SD		SD
Subjects:								
FM	1.10	0.17	2.13	1.64	1.91	1.17	1.65	0.81
PC	1.06	0.38	1.02	0.14	1.28	0.90	0.93	1.13
RF	3.10	2.69	5.58	3.99	4.81	3.84	8.86	0.79
DM	2.39	1.03	9.46	9.05	9.10	4.38	8.17	4.62
SG	2.56	0.92	3.21	2.34	4.15	3.49	2.55	1.38
IW	0.77	0.16	0.93	0.13	0.86	0.13	0.79	0.12
PR	2.54	2.56	5.25	4.73	3.26	2.28	1.35	0.44
Mean	1.93		3.13		3.63		3.47	

F (3,18) = 2.30, not significant.

Table 9.7 Mean Stereoscopic Latencies (seconds) and standard deviations (SD) for Each Subject to Make a Depth Judgement between Two Squares (24'/28' of arc) under Four Conditions of Selective Attenuation.

	Attenuation Conditions							
	Neither Display		Both Displays		Left Display		Right Display	
		SD		SD		SD		SD
Subjects:								
FM	3.78	3.41	9.21	8.97	16.79	14.03	8.94	9.81
PC	6.49	5.62	16.87	9.14	28.76	3.92	12.18	10.42
RF	2.80	2.09	7.01	3.54	22.17	10.35	10.57	8.59
DM	2.52	2.24	5.19	3.21	11.70	8.14	8.79	3.94
SG	2.55	1.22	4.84	5.90	14.57	9.99	5.17	2.80
IW	1.02	0.49	1.14	0.31	1.05	0.24	0.95	0.14
PR	7.42	5.90	5.58	4.60	5.42	4.36	4.62	5.00
Mean	3.80		7.12		14.35		7.32	

$F\ (3,18)\ 0.01 = 8.68,\ p < 0.01.$

The asymmetry scores are shown below in Table 9.8.

Table 9.8 Ocular Asymmetry Scores

Disparity Values:	12/16' of arc	24/28' of arc
Subjects:		
FM	-0.073	-0.305
PC	-0.161	-0.405
RF	+0.297	-0.354
DM	-0.054	-0.142
SG	-0.24	-0.476
IW	-0.042	-0.051
PR	-0.413	-0.079

Six subjects have right ocular asymmetries for the small disparity stereograms and all have right ocular asymmetries for the large disparity stereograms. The mean asymmetry score (ignoring the direction) is 0.18 for the small disparities and 0.26 for the large disparities.

9.11.3. Frequency of Incorrect Judgements and Failures to Discriminate Depth

i) 12/16' of arc Depth Discrimination

There were nine errors or incorrect judgements of depth made over all subjects under the following conditions; five with the left display attenuated (and all corresponding to the dominant eye as defined above), two with the right display attenuated (non-dominant eye), one for both attenuated, one for neither of the displays attenuated. On one trial with both displays attenuated a no depth judgement was made.

ii) 24/28' of arc Depth Discrimination

There were ten incorrect judgements made on the following conditions; four for left display attenuated, four for the right display attenuated and two for both scopes attenuated.

Failures to make depth judgements were made on seventeen trials and all these occurred when the left display was attenuated corresponding to the non-dominant eye as defined above. Depth of any magnitude was not reported in these trials.

9.11.4. Binocular Rivalry and Depth Discrimination Measures of Ocular Asymmetry and Sighting Dominance

The measures of ocular asymmetry derived from the binocular rivalry procedure and the two depth discrimination experiments reported in this section were compared. The correlation coefficient for the rivalry measures and the small disparity depth discrimination measures is $r = -0.10$ and for the large disparity depth discrimination measures $r = -0.38$, both of which are not significant.

In Part A, a significant correlation between real image rivalry measures and the large depth discrimination measures was reported for eight subjects. Both groups were combined (total of 15 subjects) and the correlation coefficients between the asymmetry measures were $r = 0.08$ for rivalry and the small disparate displays and $r = 0.50$ for binocular rivalry with the large disparate displays, the latter being significant at the 5% level (one-tailed). The scatterplot of the scores for the rivalry and large disparity depth discrimination measures for 15 subjects is shown in Fig 9.4.

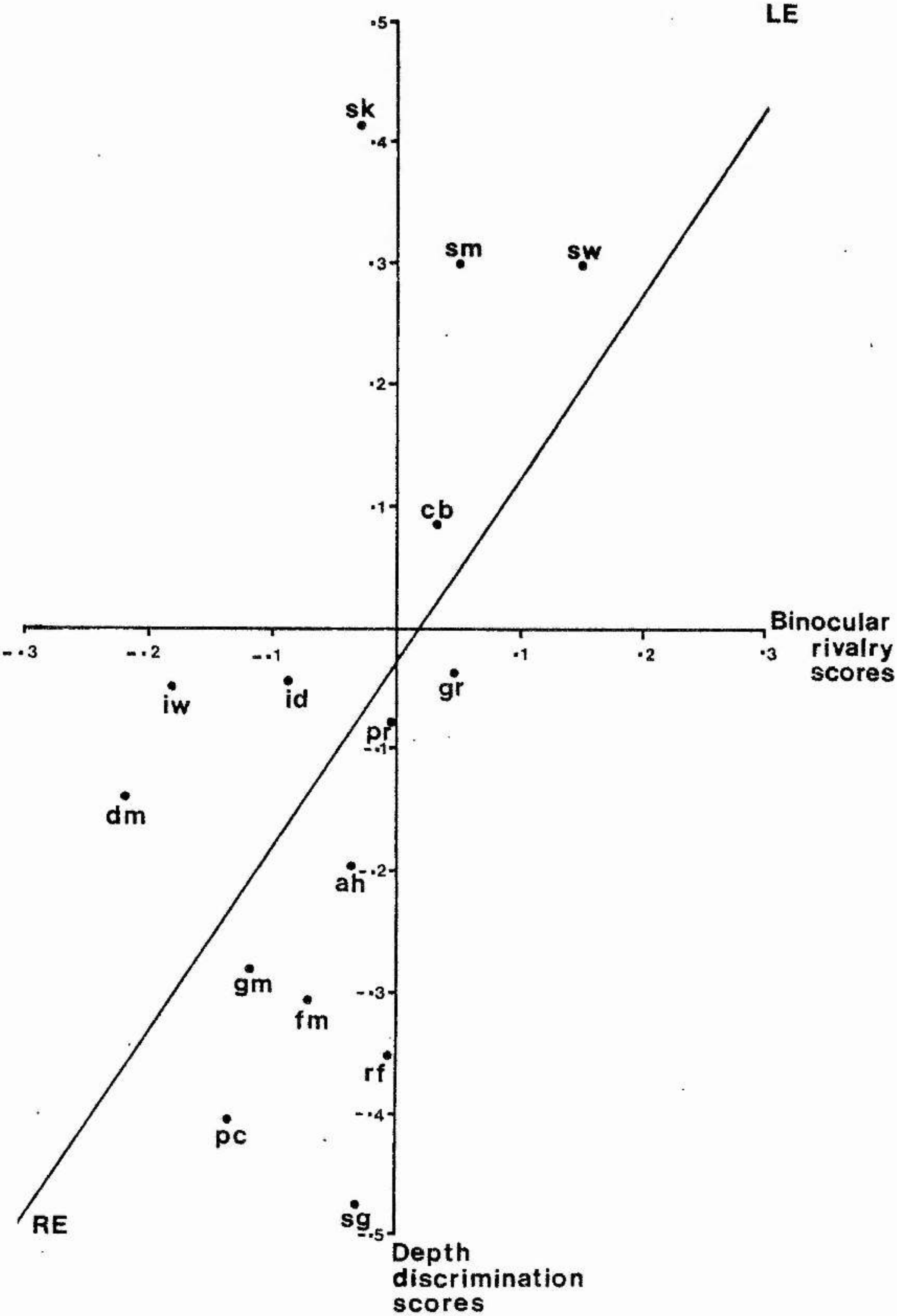
All subjects participated in a sighting test, the point test. All subjects had a right sighting eye except subjects DM and PR, who had a left sighting eye. All but two subjects (DM and PR) had a rivalrous dominant eye that was also the sighting eye. For the same five subjects the sighting eye was the dominant eye as defined by the depth discrimination measures using the large disparities.

9.12. Discussion

9.12.1. Experiment 1: Binocular Rivalry

Composites occupied 19.6% of the viewing time of rivalrous real images (over all subjects except subject FM who is excluded because of an exceptionally high percentage of composite viewing, 75.8%). There is slightly less composite viewing in this group compared to the previous group of eight subjects (24%) and this may reflect the difference in experience in viewing rivalrous afterimages.

Fig 9.4 Ocular Asymmetry Scores for Each Subject derived from the Binocular Rivalry Experiment with Real Images and the Depth Discrimination Experiment with Large Disparities (24'/28' of arc).



$r = 0.505$, $p < 0.05$ (one-tailed test).

The previous group had had experience of recording rivalry with the two response procedure before recording rivalry with the four response procedure. This group had no previous experience of the two response procedure and without the comparable experience may have underestimated the composite durations. However, subjects do show a wide difference in reporting composite occurrence.

The mean dominance score with rivalry is 0.09 which is only slightly greater than the previous subjects' results (0.067, N = 8).

9.12.1. Experiment 2: Depth Discrimination Results

The results from the depth discrimination experiments confirm the previous findings as follows:

i) Latencies to make a depth discrimination between 24' and 28' of arc were longer (mean latency of 8.15 seconds) than those for the small disparate squares of 12' and 16' of arc (mean latency is 3.24 seconds).

ii) Unequal luminance of the displays increased stereoscopic latencies above those for the equal luminance conditions for the large disparity stereograms. The left attenuated condition had longer latencies than those for the right. This may be expected given that all subjects had a right dominant eye unlike the previous group, half of whom were right dominant and half left dominant. The latencies for the small disparity displays were not differentially influenced by conditions of selective attenuation.

iii) The mean degree of asymmetry for the large disparity discrimination experiment is 0.26 and for the small it is 0.18.

9.12.3. Rivalry and Depth Discrimination Measures of Ocular Asymmetry

The mean degree of ocular asymmetry found with real image binocular rivalry procedure was again small for this new group of subjects relative to these for the depth discrimination measures. If the 20% criterion of dominance is applied to the overall mean durations each image was visible (see Table 9.4) only three subjects have a dominant eye, PC, DM and IW. The measures of asymmetry are small in degree but the results do indicate that the direction of this asymmetry can be gauged from results from only one 90 second trial of rivalry observation as reported in the preliminary session.

However, the rivalry measures were not significantly correlated with the large disparity discrimination measures of asymmetry. Both measures were significantly related for the previous group of subjects. It is not known why the results fail to replicate the previous findings although all subjects have a right ocular asymmetry on both tests. The mean degree of asymmetry for the large disparity measures (0.26) is greater than that for the rivalry measures. The subject group is smaller although both groups combined show a significant relationship between the rivalry and large disparity discrimination measures of asymmetry. This relationship is not found for the small disparity scores.

The rivalry asymmetry measures and the sighting dominance results are again not conclusive with five subjects showing agreement between the two tests. However, given the criticisms directed at dichotomous classifications for the asymmetry results, very little can be concluded from the sighting dominance results and rivalry asymmetry measures especially given that the latter scores are quite small.

9.13. Summary of the Experiments in Chapter 9: Parts A and B

The chapter was divided into two parts. In Part A, a group of subjects (N = 8) with mixed rivalry asymmetry measures participated in two depth discrimination experiments. In Part B, seven subjects with right ocular rivalry asymmetries participated in the same experiments as a replication study. The first hypothesis was confirmed. Both groups showed that the time taken to make a depth discrimination between two squares differing in 4' of arc were longer for baseline disparities of 24' of arc relative to small disparities with a baseline of 12' of arc. The increase in latencies probably reflects the involvement of vergence eye movements required to fuse large disparity displays.

The second hypothesis was partially confirmed: both groups showed differential increases in response times for the four conditions of selective attenuation with the large disparity displays only. The two conditions of unequal attenuation had longer latencies than the two conditions of equal attenuation. There was no significant variation in latencies for the small disparate displays over these four conditions.

Measures of ocular asymmetry were derived from the mean latencies for the two conditions of unequal attenuation. These asymmetry scores gave both direction and degree of asymmetry. The differential effects of selective attenuation on response times interacted with the disparity values of the displays and this was also reflected in the measures of asymmetry derived from the two experiments for both groups of subjects. The mean degree of asymmetry for the large disparity displays was greater (mean of 0.21 for 8 subjects and 0.26 for the seven subjects) than those derived from the small disparity displays (mean of 0.10 for 8 subjects and 0.18 for the seven subjects). These results suggest that eye movements may be involved in the ocular asymmetry effects. It was proposed (in Part A) that unequal luminance of the displays may increase the time taken for one signal to arrive at the binocular site where a comparison is made between the two signals in order to compute the extent and direction of the vergence movements to be executed. The measures of ocular asymmetry derived from the large disparity experiment may reflect an inherent differential in processing speed of the signals from the two eyes.

These measures were compared to the binocular rivalry measures of ocular asymmetry. In Part A, a significant relationship was reported between the large depth discrimination measures and rivalry measures (5% level) but not with small disparity measures. The second group of subjects in Part B did not show a significant relationship between the large disparity discrimination and rivalry measures although all seven subjects had right ocular asymmetries in both procedures. This was not found for the small disparity discrimination measures. When both groups were combined a significant result was reported at the 5% level. There was no systematic relationship between the sighting dominance results and the asymmetry measures derived from the large and small depth discrimination experiments for both groups of subjects.

It was suggested that depth discriminations between disparities of 12' and 16' of arc may be relatively easy and the short latencies may mask any effect of selective attenuation on response times. If "floor" effects are operating the experiments reported in Parts A and B using small disparities may not provide a sufficient test for investigating ocular asymmetries in a binocular process that does not involve vergence eye movements.

CHAPTER 10

PART A: Depth Discrimination Measures of Ocular Asymmetry using "Scrambled" (1) Random-dot Stereograms.

10.1. Introduction

A measure of ocular asymmetry has been reported for two groups of subjects based on the latencies to make depth discriminations with random-dot stereograms which were selective attenuated to the two eyes. This measure of asymmetry gave both the direction and degree of the asymmetry and was found to be greater when the stereograms had a large disparity. When the disparity values were small (12/16' of arc) selective attenuation of the two displays did not significantly affect the latencies to make the depth discrimination. These results are consistent with an eye movement hypothesis. The results from the large disparity depth discrimination experiment reflect the need to make vergence eye movements.

However, it was suggested that the small disparity depth discrimination experimental results may be confounded by "floor" effects ie. the results may have been masked by the ease of the task. The experiments in this chapter were designed to make the depth discrimination task more difficult to allow any asymmetry effects to show up. To make the task more difficult and to increase latencies to make depth discriminations, the stereograms were "scrambled" ie. the displays were partially complemented. In addition smaller disparities were chosen in order to be more confident that eye movements were not involved in the depth discriminations for the small disparate displays.

(1)The word "scrambled" is used to denote random-dot stereograms that have had a percentage of their elements or dots complemented: some black dots are made white, some white dots are made black. The dots to be complemented are randomly distributed across the array.

10.1.2. "Scrambled" Random-dot Stereograms

Julesz (1971, p.p.274-275) reported that with an increasing percentage of complemented dots in random-dot displays the ability to identify a depth plane decreases. If all elements in the random-dot stereogram are complemented, one stereo field becomes the photographic negative of the other and depth is not possible (Julesz, 1963a). If some of the elements are complemented ie. the displays are "scrambled", imperfect fusions may occur making the task more difficult. It would be expected that latencies to make a depth discrimination for these "scrambled" displays would be greater relative to the "unscrambled" displays. This would be expected for both small and large disparity displays.

Complementing the displays makes the comparison of the two displays more difficult but it would not be expected to interact with conditions of selective attenuation or effects of asymmetry.

10.1.3. Hypotheses to be Tested

Two experiments are reported in Part A, one with small disparate squares of 8 and 12' of arc and one with large disparate squares of 24 and 28' of arc to investigate the following hypotheses:

1). That latencies would increase for both the large and small disparity "scrambled" stereograms relative to the latencies for the "unscrambled" displays reported in chapter 9, Part B.

2). That an increase in latencies for the small disparity displays above the "floor" level would result in marked asymmetries between the two conditions of unequal attenuation.

3). That "scrambling" would not interact with conditions of selective attenuation and therefore reflect a quantitative increase only.

10.2. Method

10.2.1. Subjects

The seven subjects from the previous experiment participated in these two experiments. There was a three month interval between these experiments and the previous depth discrimination measures reported in chapter 9.

10.2.2. Apparatus

The stereograms were displayed in the modified stereoscope arrangement as described in chapter 9, page 119 and Fig 9.1.

10.2.3. The Stereograms

The random-dot stereograms were generated on-line by the computer and displayed on the CRT screens. The percentage of dots in the 64 x 64 dot matrix to be "scrambled" (complemented) were specified at the start of each experiment. Each stereogram displayed during the experimental session for each subject had this constant percentage of "scrambled" elements despite the random configuration of the displays being changed from trial to trial.

10.2.4. Procedure

Subjects were shown a series of stereograms portraying two square areas of 16' and 20' of arc disparity before the beginning of the experiment. These displays had 15 percent of the dots complemented. If subjects were unable to see depth at all with these displays, the "scrambling" was reduced to 10 per cent. For two subjects FM and RF, the percentage "scrambling" for the large disparate displays was 10 percent. For the small disparity display "scrambling" had to be increased from 15 to 20% for three subjects, FM, SG and IW because of their ability (ie. short response times) to see the depth differences with 15% of the dots "scrambled".

The procedure was the same as in the previous experiments for the depth discrimination experiments. There were two experiments, 1) displays of 8' and 12' of arc disparity and 2) displays of 24' and 28' of arc disparity. The four conditions of selective attenuation were the same as in the previous experiments and administered randomly over the 40 trials.

Subjects were told that the square areas may not appear as well defined in depth in these two experimental sessions as with the previous "unscrambled" stereograms. They were told to press the switch key as soon as the two areas could be discriminated in depth even though they may appear ill defined in shape. Subjects participated in the small disparity experiment first.

10.3. Results

10.3.1. Stereoscopic Latencies for the Four Conditions of Selective Attenuation

i) Experiment 1: 8'/12' of arc Depth Discrimination

Table 10.1 shows the mean stereoscopic latencies for each subject under the four conditions of selective attenuation. The overall mean latency to make a depth discrimination is 5.69 seconds. The mean latency is longer for the left display attenuated condition relative to the remaining three. An analysis of variance carried out on these latencies, (four conditions and ten trials) showed a significant difference over conditions of selective attenuation but only at the 5% level ($F = 3.3161$, df 3, 18, $p<0.05$). A planned comparison between the means showed that the latencies for the left display attenuated condition was significantly longer than the right display attenuated condition ($F = 6.65$, df 1, 18, $p<0.05$). This is not surprising given that all subjects were found to have right ocular asymmetries on the rivalry task and on the large and small "unscrambled" depth discrimination tasks (apart from one subject on the latter, RF). However, the latencies for the unequal luminance condition were not significantly different from the latencies for the equal luminance condition ($F = 3.25$, df 1, 18, not significant). (See Appendix F for the summary tables of the analyses of variance and planned comparisons).

ii) Experiment 2: 24'/28' of arc Depth Discrimination

Table 10.2 shows the mean latencies for the large disparity displays for the four experimental conditions. The overall mean latency is 9.94 seconds. It can be seen that the two conditions of unequal luminance have the longer response times for discrimination of depth than the two equal luminance conditions. This difference was confirmed by the results of an analysis of variance carried out as above; conditions were significantly different ($F = 4.4012$, df 3,18, $p<0.025$) and a planned comparison of the means resulted in a significantly longer latency for the two conditions of unequal attenuation ($F = 8.89$, df 1, 18, $p<0.01$).

Table 10.1 Mean Stereoscopic Latencies (seconds) and standard deviations (SD) for Each Subject to Make a Depth Judgement between Two Squares (8'/12' of arc) under Four Conditions of Selective Attenuation.

	Attenuation Conditions							
	Neither Display		Both Displays		Left Display		Right Display	
		SD		SD		SD		SD
Subjects:								
FM*	11.06	11.89	8.67	9.65	7.77	6.90	6.63	8.87
PC	3.61	4.09	3.48	4.66	5.81	6.05	2.60	1.49
RF	4.63	3.27	4.80	2.07	13.14	9.66	5.13	2.48
DM	5.73	4.00	6.16	3.53	9.35	5.67	8.50	5.05
SG*	6.27	5.25	6.93	8.26	12.07	8.79	5.70	3.20
IW*	0.95	0.30	0.90	0.20	0.91	0.27	1.16	0.43
PR	3.25	2.48	4.02	2.36	4.84	2.69	5.37	3.07
Mean	5.07		4.99		7.70		5.01	

$F\ (3,18)\ 0.05 = 3.32,\ p < 0.05.$

* - 20% of the display elements "scrambled".

Table 10.2 Mean Stereoscopic Latencies (seconds) and standard deviations (SD) for Each Subject to Make a Depth Judgement between Two Squares (24'/28' of arc) under Four Conditions of Selective Attenuation.

	Attenuation Conditions							
	Neither Display		Both Displays		Left Display		Right Display	
		SD		SD		SD		SD
Subjects:								
FM*	2.31	1.14	6.72	8.49	6.47	4.96	8.78	8.53
PC	6.68	4.11	7.18	6.53	17.06	10.33	4.62	1.85
RF*	8.80	7.04	15.00	11.42	25.22	8.11	15.19	10.67
DM	12.89	8.84	17.41	9.90	14.06	8.68	23.32	7.36
SG	5.62	1.46	5.12	1.56	19.86	8.78	6.75	3.21
IW	1.38	0.36	1.58	0.27	7.11	8.20	1.34	0.33
PR	6.80	4.17	9.72	3.82	8.48	4.73	12.75	9.82
Mean	6.35		8.96		14.04		10.39	

$F\ (3,18)\ 0.02 = 4.40,\ p < 0.02.$

10.3.2. Does "Scrambling" Increase Stereoscopic Latencies?

Fig 10.1 shows the mean latencies for large and small disparity experiments for "unscrambled" stereograms reported in the previous chapter (chapter 9, Part B) and for those reported in this chapter. The mean latencies for each disparity level and display type (that is, "scrambled"/"unscrambled") are based on the summed latencies for the four conditions of selective attenuation averaged over all subjects. The first hypothesis is confirmed, response times to make a depth discrimination are increased for "scrambled" displays whatever the disparity value. An increase in the disparity value also increased the reaction times for both types of display. The latencies for both experiments reported here and in chapter 9, Part B were entered into an analysis of variance, the factors were; disparity (small/large), type of display ("scrambled"/"unscrambled"), trials (10) and conditions of selective attenuation (4). The effect of "scrambling" did not increase stereopsis latencies significantly ($F = 5.80$, df 1,6, $p=0.053$). Large disparity depth discriminations significantly increased stereopsis latencies above those for the small disparate displays ($F = 15.75$, df, 1, 6, $p<0.008$). The interaction of disparity value and type of display also failed to reach significance (Fig 10.2).

10.3.3. Measures of Ocular Asymmetry

In Tables 10.1 and 10.2 it can be seen that the mean stereoscopic latencies for the left display attenuated condition and the right display attenuated condition are not equivalent. A measure of ocular asymmetry was derived from these mean latencies using the formula outlined on page 126 with the rationale outlined on page 115. The asymmetry scores derived from the latencies for the "scrambled" displays are shown below in Table 10.3. A positive value indicates an asymmetry to the left eye, a negative value or asymmetry to the right eye.

Fig 10.1 Mean Stereoscopic Latencies (seconds) for Small and Large Disparity, "Scrambled" and "Unscrambled" (see Chapter 9) Stereograms (averaged over the conditions of selective attenuation and subjects, N=7).

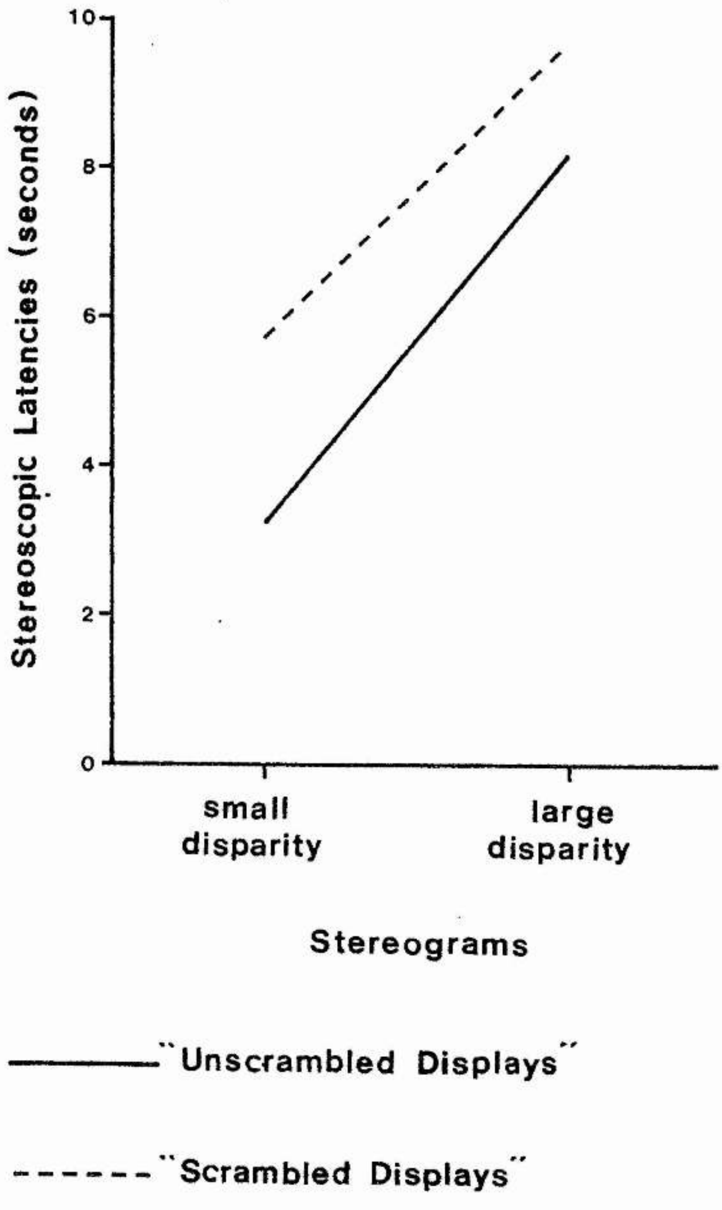


Fig 10.2 Mean Stereoscopic Latencies (seconds) for Unequal and Equal Luminance Conditions of Selective Attenuation for Small and Large Disparity, "Scrambled" and "Unscrambled" Stereograms (averaged over all subjects).

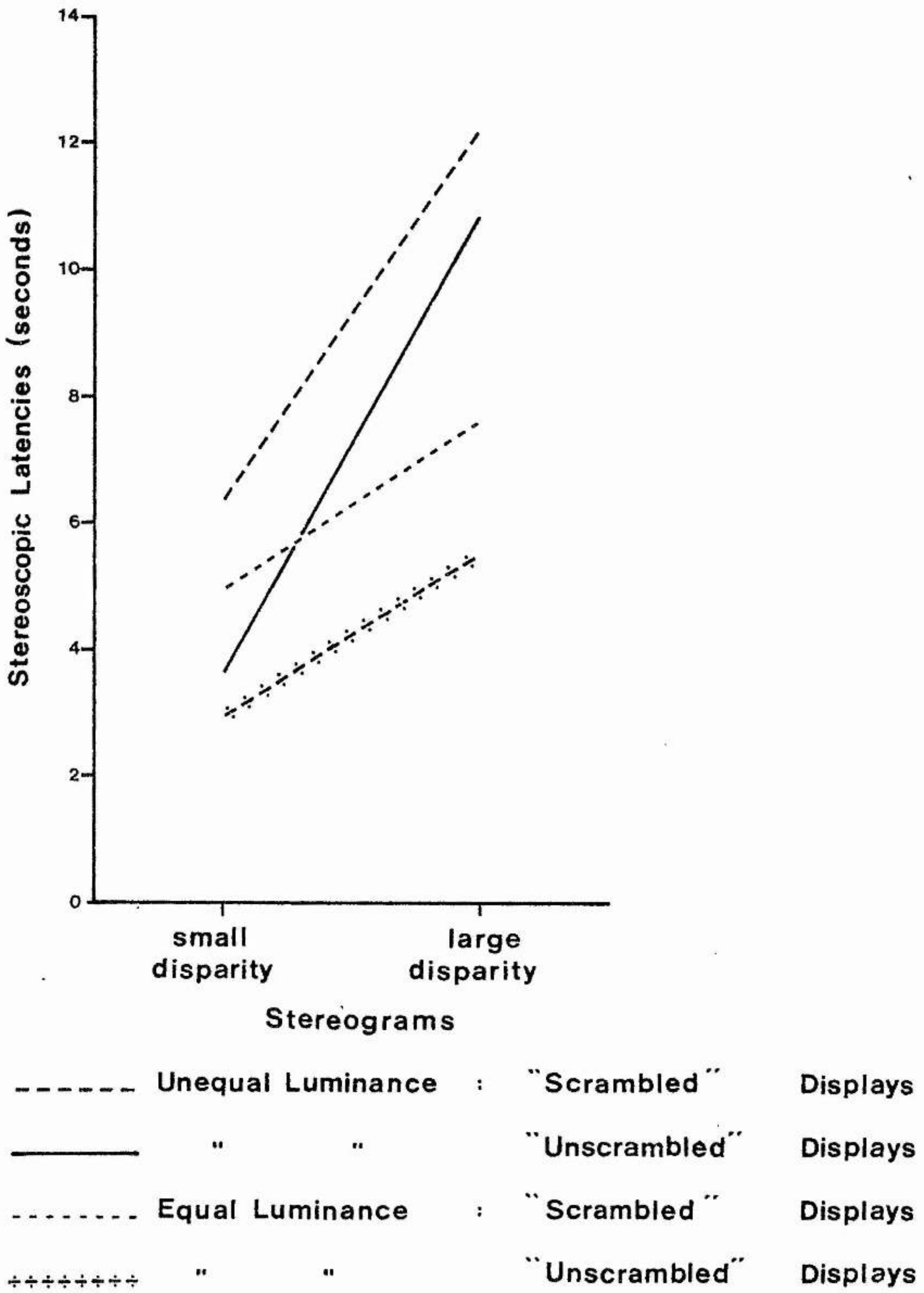


Table 10.3 Ocular Asymmetry Scores ("Scrambled" stereograms)

Disparity Values:	8/12' of arc	24/28' of arc
Subjects:		
FM	-0.08	+0.15
PC	-0.38	-0.57
RF	-0.40	-0.25
DM	-0.05	+0.25
SG	-0.36	-0.49
IW	+0.10	-0.68
PR	+0.05	+0.20

Five subjects have right ocular asymmetries for the small disparity displays and four for the large disparity displays. The mean degree of asymmetry is 0.20 and 0.37 for the small and large disparity displays respectively (the direction of the asymmetry is ignored).

10.3.4. Frequency of Incorrect Judgements and Failures to Discriminate Depth

i) Experiment 1: 8/12' of arc Depth Discrimination

There were no errors in judgements of depth. However, there were no depth judgements within the 30 seconds of viewing on three trials of unequal luminance and three trials of equal luminance of the displays.

ii) Experiment 2: 24/28' of arc Depth Discrimination

There were 37 depth discrimination errors out of a total of 280 trials. There were 23 made when the displays were of unequal luminance, 10 of which ocurred when the non-dominant eye was attenuated as defined above.

On 28 trials no depth difference could be distinguished, 6 of these being for equal luminance conditions and 22 for unequal luminance conditions; 19 for attenuation of the non-dominant eye, 3 for attenuation of the dominant eye. Dominance is defined by the above table.

10.3.5. Binocular Rivalry Measures and Depth Discrimination Measures of Ocular Asymmetry

Figures 10.3 to 10.6 show the scatterplots for the asymmetry measures derived from the binocular real image rivalry procedure (chapter 9, Part B) and the four depth discrimination experiments; two with "unscrambled" displays (chapter 9, Part A) and two with "scrambled" displays as reported in this chapter (Part A).

There is a weak relationship between the asymmetry measures of rivalry and the large disparity "scrambled" discrimination measures (see Fig 10.6) but not with the other depth discrimination measures. The asymmetry measures derived from the small disparity displays show a negative relationship with the rivalry measures regardless of the presence or absence of "scrambling".

The mean degree of asymmetry for the large disparity "scrambled" displays is 0.37 but the asymmetry measures for the small disparity "scrambled" displays were not markedly increased above that reported for the "unscrambled" displays in chapter 9, Parts A and B.

10.4 Discussion

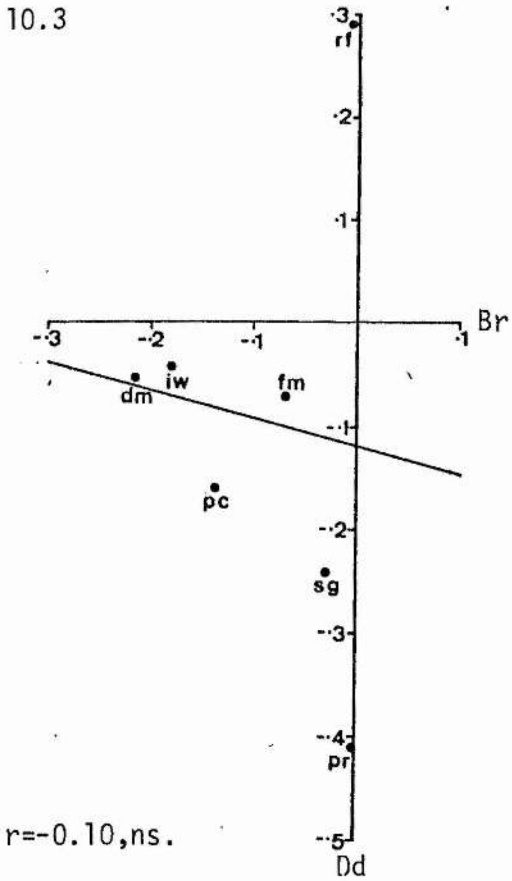
10.4.1. Stereoscopic Latencies for the Small and Large Disparity Stereograms

Several subjects commented on the appearance of the random-dot displays in this experiment relative to the previous "unscrambled" stereograms. The surfaces in depth were described as being ill-defined and the "squares" had "rounded corners and ragged edges". The stereograms were also described as "patchy" in luminance. Similar reports have been given to describe stereograms with less than a 100% correlation between the two matrices (Julesz, 1971; Gulick and Lawson, 1976).

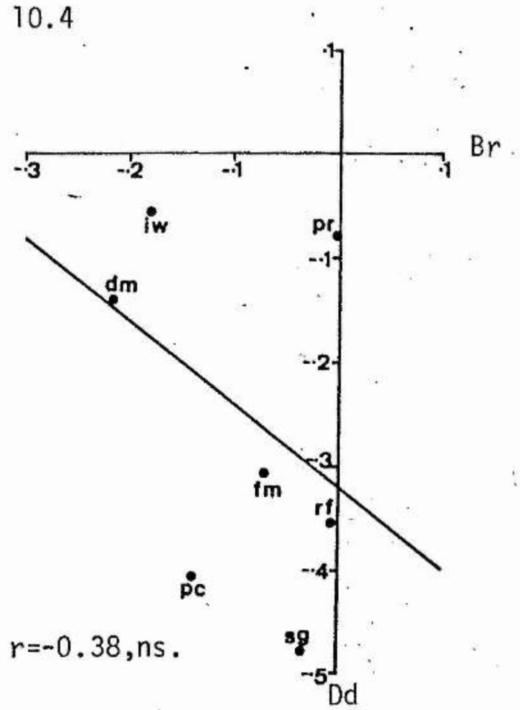
The first hypothesis was confirmed. Latencies were increased for both small and large disparity "scrambled" displays although not significantly. Small disparity discrimination latencies increased from a mean of 3.24 seconds for "unscrambled" to 5.69 seconds for "scrambled" displays.

Fig 10.3-10.6 Ocular Asymmetry Scores from the Binocular Rivalry Experiment and the Depth Discrimination Scores.

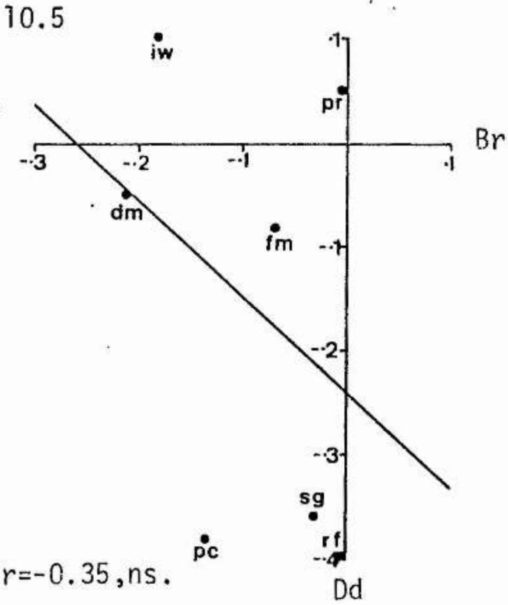
10.3



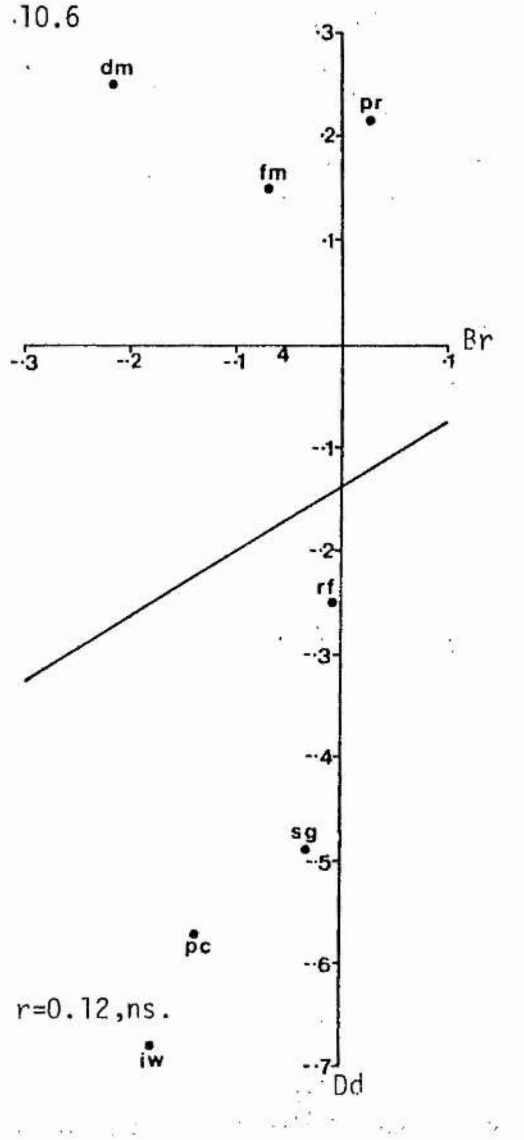
10.4



10.5



10.6



Br - Binocular Rivalry
Dd - Depth Discrimination
10.3 - Small "Unscrambled" Displays
10.4 - Large "Unscrambled" Displays
10.5 - Small "Scrambled" Displays
10.6 - Large "Scrambled" Displays

The experiments with the "scrambled" stereograms were designed to test whether increasing latencies for the small disparity stereograms above the "floor" level would result in a marked asymmetry between the two conditions of unequal luminance. The results fail to confirm the second hypothesis that conditions of selective attenuation influence response latencies with small disparity displays in the depth discrimination procedure. Unequal luminance with the left display attenuated resulted in significantly longer response times but only at the 5% level. This result is not surprising if all subjects have a right ocular asymmetry as measured by the binocular rivalry procedure and the large disparity and small disparity procedures (except subject RF). However, the latencies for small disparities for each subject under the four experimental conditions show greater variability relative to the latencies found for the "unscrambled" displays (compare Table 10.1 with Table 9.6). The increase in latencies with "scrambled" displays suggests that a reduced correlation presents a difficult fusional task: some elements within the disparate areas will have zero-disparity possibly increasing the ambiguity to the fusional solution. The greater variability in latencies may reflect the different random configurations of the "scrambled" elements in each stereogram that changed from one trial to another. However, despite this difficulty there were no incorrect depth discriminations.

The stereoscopic latencies for the large disparity displays showed an increase in mean values from 8.15 second, "unscrambled" to 9.90 seconds "scrambled". Given that the fusional process in stereopsis is affected by "scrambling" as shown for the small disparities above, it would have been expected that the response times to make a depth discrimination would have been increased significantly more for large disparity "scrambled" stereograms than in this case. Disparity information must be resolved prior and/or during the execution of vergence movements to bring about the correct registration of the two stereo-fields. If after initial convergence, disparity information has still not been resolved, correction of errors will be delayed. It is also possible that the hysteresis effect (Fender and Julesz, 1967) will be disrupted for "scrambled" displays; fewer "locked" elements of the two displays may increase the instability of the fused areas during further vergence shifts. If more saccades are made in scanning the disparate areas, which is probable given that the "squares" were not well defined after fusion, fusion will be lost more frequently. Some evidence for this comes from the frequency of failures to discriminate depth which constituted 10% of the total number of trials, and frequency of errors, 13% of the total number of trials which possibly reflects partial or incorrect fusion. However, this does not appear to be reflected in significantly longer response latencies. Possible practice effects may have reduced the time taken to achieve the correct fusion. This will be discussed below.

The third hypothesis was confirmed. The effect of unequal luminance of the large disparity displays on stereoscopic response times was similar to that reported for "unscrambled" displays in chapter 9: stereoscopic latencies were longer for the unequal luminance conditions relative to the equal luminance conditions.

10.4.2. Measures of Ocular Asymmetry

The mean degree of asymmetry found for the small "scrambled" displays (0.20) is similar to that found for the "unscrambled" displays (0.18). The small disparity scores were not related to the binocular rivalry measures of ocular asymmetry although five subjects had right ocular asymmetries on both tasks.

However, the asymmetry measures derived from the large disparity discrimination experiment had a mean degree value of 0.37. These measures show a positive correlation with the binocular rivalry measures although it is not significant (Fig 10.6 compare to Fig 10.4).

10.4.3. The Effects of Practice on Depth Discriminations with Random-dot Stereograms

Learning effects with random-dot stereograms have already been discussed with respect to vergence eye movements. Evidence suggests that learning to fuse and see depth with these displays is dependent on "on-line" guidance for fusional vergence movements and saccades as provided by the addition of monocular outline features (Frisby and Clatworthy, 1975; Saye and Frisby, 1975). Therefore, the stereoscopic latencies would not be expected to decrease over successive presentations of random-dot stereograms used in these experiments. This was supported by the results with large disparity displays reported in chapter 9 and those reported here.

However, successive practice at fusing random-dot stereograms may result in learning effects not directly associated with vergence control strategies over the displays. The disparity values in each experimental session were constant ie. either two small disparity levels (8/12' or 12/16' of arc) or two large disparity levels (24/28' of arc). It is possible, given a fixed interval between trials that subjects may have made anticipatory vergence movements as the display appeared on the screen (Mayhew and Frisby, 1979). It is possible that the amount of disparity in the displays for each experimental session was retained (Julesz, 1971, p 217) or that a viewing strategy after considerable practice with these displays was retained over long periods (Maccracken, Bourne and Hayes, 1977). For example, familiarity with the task together with knowledge of the location and size of the disparate areas may have reduced the occurrence of saccadic scanning movements (except possibly with "scrambled" large disparity displays). These factors may result in less viewing time required for stereoscopic discriminations to be made although only after considerably practice (ie. more than 40 trials).

The results from this section (Part A) will be summarised with the results reported in the following section (Part B) at the end of chapter 10.

Part B: A Control Experiment Using a Random Sequence of Small and Large Disparity Trials.

10.5. Introduction

Measures of ocular asymmetry have been reported for large and small disparity stereograms derived from two conditions of selective attenuation. However, the results suggest that the ocular asymmetry effects may involve eye movements; the scores from the small disparity displays were small and were also unrelated to rivalry measures of ocular asymmetry. This was found for small disparity displays that had been "scrambled" possibly eradicating "floor" effects. In all these experiments stereograms with one baseline disparity value (ie. 8/12' or 24/28' of arc) had been presented as a block of trials which may have influenced any viewing strategies. The differential results for the two disparity stereograms for the conditions of selective attenuation may be an artefact of this procedure.

The experiment reported in Part B was designed to control for any possible effects of viewing strategy on response times for depth discriminations. A random sequence of small and large disparate stereograms both "scrambled" and "unscrambled" were presented to a group of subjects naive as to viewing random-dot stereograms. The aim of the experiment was to test the hypothesis that ocular asymmetry effects reported in the previous chapters (ie. based on unequal luminance of large disparate displays only) would be derived from the same displays but using a different procedure of presentation ie. a random sequence of all stereograms.

A group of subjects naive as to viewing random-dot stereograms were given a random presentation of "unscrambled" and "scrambled" stereograms at both disparity values. This approach would preclude any influence of practice effects or strategies for depth discrimination developing and carrying over from one trial to another.

10.6. Method

10.6.1 Subjects

Twenty subjects participated in the experiment, all members of St Andrews University. All had good stereoscopic vision.

10.6.2. Apparatus

The experimental set up was the same as for all the depth discrimination experiments except the modulation of the brightness of the displays was controlled on-line by the computer.

10.6.3. The Stereograms

The random-dot stereograms were generated on the CRT screens by the computer. The disparity levels were 8/12' of arc and 24/28' of arc. Two types of stereogram were generated "unscrambled" and "scrambled". The "scrambled" stereograms had 15% of the dots complemented and this was constant for all subjects. The random configuration of each stereogram displayed was changed from trial to trial.

10.6.4. Procedure

Subjects were given six practice trials before the experiment began. A 3-D model of a fused stereogram showing two square areas standing above the surround, one above and one below the fixation point was shown to each subject. The procedure was essentially the same as in the previous experiments except for the following modifications:

1) Subjects were given 64 trials in one experimental session. There were sixteen conditions, 4 trials in each as shown below:

Table 10.4 The Experimental Conditions (4 trials for each condition)

Disparity values displays	Type of display	Attenuation of left/right displays
Small Disparity 8/12'of arc	"Unscrambled"	Neither
		Both
		Left
		Right
	"Scrambled"	Neither
		Both
		Left
		Right
Large Disparity 24/28'of arc	"Unscrambled"	Neither
		Both
		Left
		Right
	"Scrambled"	Neither
		Both
		Left
		Right

2) The trials were presented in a random sequence, the sequence being the same for each subject. The square with the higher disparity value of the two was also randomly assigned to the top or bottom square throughout the trials as in the previous experiments.

10.7. Results

10.7.1. Mean Stereoscopic Latencies for the Different Stereograms

It was found that on some trials subjects pressed the key switch indicating a discrimination had been made simultaneously as to the removal of the stereogram from the screens. On these trials a value of 30 seconds was substituted.

The mean latencies over all subjects and conditions for the small disparity "unscrambled" and "scrambled" displays were 3.37 and 6.88 seconds respectively. The mean latencies for the large disparity "unscrambled" and "scrambled" displays were 6.78 and 17.06 seconds respectively. "Scrambling" increases response times by over a factor of 2 for both disparities.

An analysis of variance was carried out on the stereoscopic latencies for each subject. The factors entered into the analysis were; disparity (small and large), type of display ("unscrambled"/"scrambled"), conditions of selective attenuation (neither, both, left, right displays) and trials (4 in each condition). The summary of the analysis of variance and post-hoc comparison tests between the means using the t-test, are shown in Appendix F. The results are as follows:

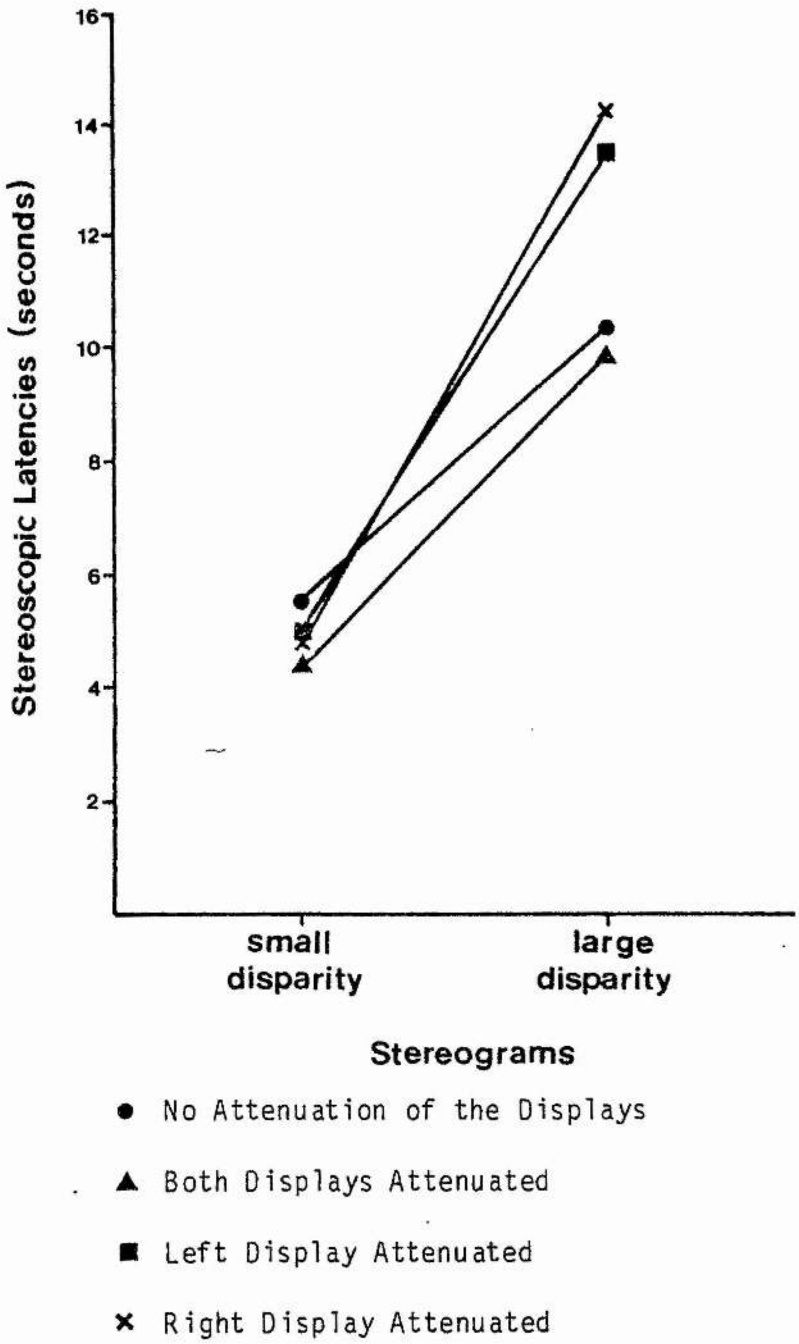
1) There was a significant increase in time taken to make a depth discrimination with an increase in the disparity values from 8/12' to 24/28' of arc which confirms previous findings (see chapter 9 and Part A, chapter 10) ($F = 68.38$, df 1, 19, $p<0.00001$).

2) "Scrambling" of the stereograms also significantly increased response times from an overall mean 5.12 second for the "unscrambled" displays to 11.92 seconds for the "scrambled" stereograms ($F = 76.94$, df 1, 19, $p<0.00001$).

3) The interaction between type of display ("unscrambled"/"scrambled") and the disparity level was also significant ($F = 45.37$ df 1, 19, $p<0.0001$). "Scrambling" produced a greater increase in latencies for the large disparity display than for the small "scrambled" displays relative to the "unscrambled" equivalents. The differential for the large disparity stereograms is 10.18 seconds and 3.52 seconds for the small disparities. However, these increases were significant, for both the large disparate ($t = 10.43$, df 33, $p<0.0005$) and small disparate displays ($t = 3.70$, df 33, $p<0.005$).

4) Fig 10.7 shows the mean latencies for the four conditions of selective attenuation for the two disparity values. The interaction was significant ($F = 9.25$, df 3, 57, $p<0.00001$).

Fig 10.7 Mean Stereoscopic Latencies (seconds) for Four Conditions of Selective Attenuation and Two Levels of Disparity (averaged over 20 subjects).



Unequal luminance increased the latencies relative to equal luminance of the displays for the large disparities only ($t = 6.77$, df 108, $p<0.0005$). Stereoscopic latencies were not significantly different for the equal and unequal luminance conditions for the small disparity conditions ($t = 0.206$, df 108, not significant).

5) There was a significant three-way interaction between disparity, type of display and conditions of attenuation ($F = 3.80$, df 3, 57, $p<0.02$). This is shown in Fig 10.8. A series of post-hoc comparison tests were carried out between the mean stereoscopic latencies (using the one-tailed test, see Appendix F, Table 10.10F) with the following results:

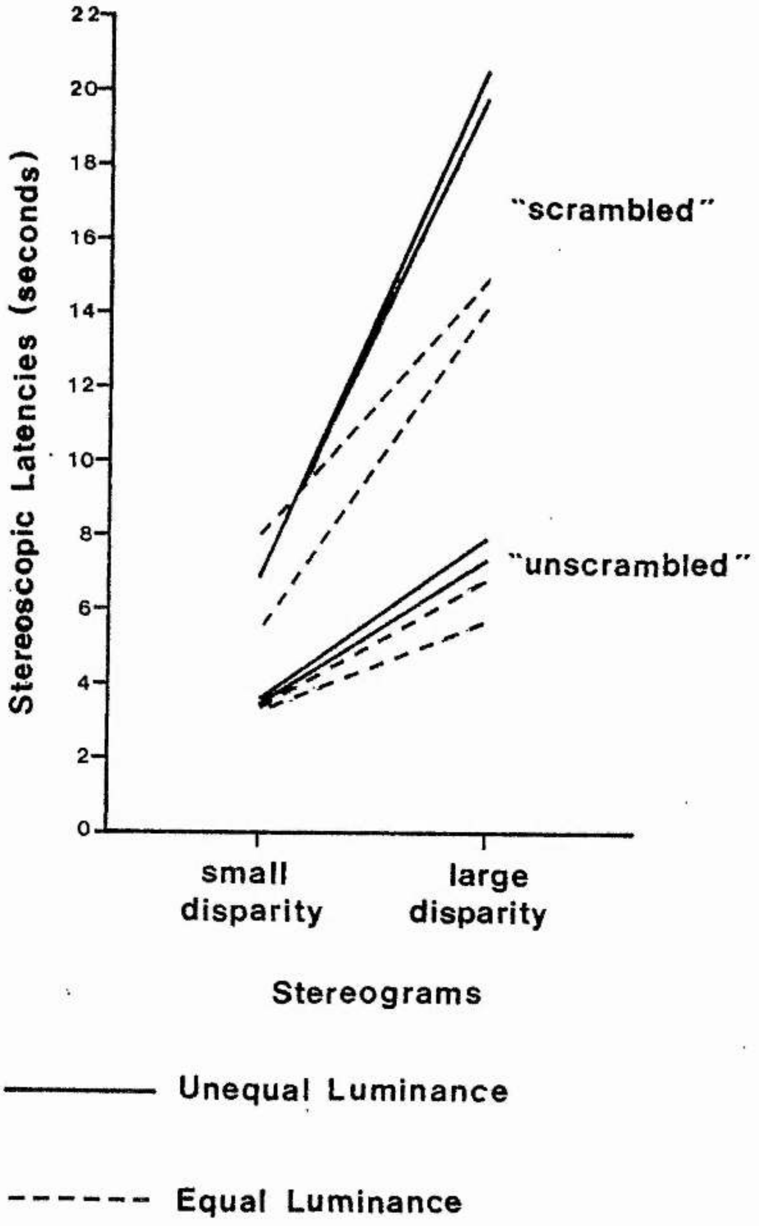
   a) The mean latencies for the equal and unequal luminance conditions were not significantly different for the small disparity "unscrambled" displays ($t = 0.22$, df 108, not significant). This confirms the results of the previous experiment with eight and seven subjects (see chapter 9, Parts A and B).

   b) The mean stereoscopic latencies for the equal and unequal luminance conditions were not significantly different for the small disparity "scrambled" displays ($t = 1.00$, df 108, not significant). This confirms the results in Part A of this chapter for seven subjects.

   c) The mean stereoscopic latencies for the equal and unequal luminance conditions were significantly different for the large disparity "unscrambled" displays ($t = 1.80$, df 108, $p<0.05$) confirming the results in chapter 9, Parts A and B.

   d) The mean stereoscopic latencies for the equal and unequal luminance conditions were significantly different for the large disparity "scrambled" displays ($t = 7.80$, df 108, $p<0.0005$). Results confirm those reported in Part A of this chapter.

Fig 10.8 Mean Stereoscopic Latencies (seconds) for 16 Experimental Conditions (disparity X selective attenuation X "scrambled"/"unscrambled") over all Subjects.



10.7.2. Measures of Ocular Asymmetry

Table 10.5 shows the asymmetry scores for each subject for the four display conditions. The asymmetry measures were derived from the mean latencies for the two unequal luminance conditions (4 trials in each) using the formula shown on page 126. A positive value indicates a left ocular asymmetry, a negative value a right ocular asymmetry.

It can be seen that the mean degree of asymmetry is greater for the large disparity displays. Also the range of asymmetry scores for this sample of twenty subjects is greater for the two large disparity displays. Unfortunately, no rivalry measures of asymmetry were collected for this group of subjects.

10.7.3. Frequency of Incorrect Judgements and Failures to Discriminate Depth

Errors in judgement of the depth difference between the two disparate square areas were made on 122 trials out of a total of 1280 trials over all subjects (9.3% of the total). Table 10.6 shows the frequency distribution of these errors.

Table 10.6 Frequency of errors

Disparity value:	Small, 8/12' of arc				Large, 24/28' of arc			
Conditions of Attenuation :	Neither	Both	Left	Right	Neither	Both	Left	Right
Display Type:								
"Unscrambled"	0	0	1	0	1	4	8	8
"Scrambled"	8	1	3	4	25	16	23	20

More errors were made with the large disparity displays. "Scrambling" increases the number of errors for both the large and small disparity displays. Selective attenuation has no differential effect on the distribution of these error scores. Twenty three errors were made when the non-dominant eye was attenuated for the "scrambled" large disparity displays, dominance is defined by the asymmetry scores from the above

Table 10.5 Ocular Asymmetry Scores

Disparity Values:	Small, 8'/12' of arc		Large, 24'/28' of arc	
Type of Display:	"Unscrambled"	"Scrambled"	"Unscrambled"	"Scrambled"
Subjects:				
EM	-0.04	-0.17	-0.37	-0.07
JE	+0.03	+0.16	+0.04	-0.07
SD	-0.11	-0.10	-0.15	+0.71
RH	-0.04	-0.27	+0.22	+0.57
AG	-0.07	-0.02	-0.29	+0.16
JS	+0.06	+0.31	-0.23	-0.23
SJ	+0.02	-0.17	-0.04	+0.08
JP	+0.01	-0.05	+0.14	-0.01
EB	-0.43	+0.05	-0.09	-0.21
NT	-0.004	-0.04	-0.16	-0.29
JN	+0.15	-0.07	-0.03	-0.003
BB	-0.08	+0.14	+0.03	-0.04
PS	+0.13	-0.03	-0.05	+0.008
ES	+0.25	-0.32	-0.03	+0.07
SWa	-0.03	+0.11	+0.47	+0.18
JC	-0.07	-0.18	-0.11	+0.08
ALi	+0.005	-0.15	+0.10	-0.13
PL	+0.01	-0.01	+0.17	-0.14
AT	+0.18	+0.22	+0.41	+0.008
Mean Degree(1) of Asymmetry	+0.094	+0.13	+0.16	+0.15
Range of Asymmetry Scores	-0.43 - +0.25	-0.32 - +0.31	-0.37 -+0.47	-0.29 -+0.71

table for the appropriate stereogram display. Seven errors were made with the non-dominant eye attenuated for the large "unscrambled" stereogram, dominance is defined by the above table.

Table 10.7 shows the frequency distribution of the failures to discriminate depth within the 30 seconds of viewing. Only 5% of the total number of trials fell within this category (ie. 62).

Table 10.7 Frequency of Failures of Failures to Discriminate Depth

Disparity value:	Small, 8/12' of arc				Large, 24/28' of arc			
Conditions of Attenuation :	Neither	Both	Left	Right	Neither	Both	Left	Right
Display Type:								
"Unscrambled"	0	0	0	0	0	0	0	1
"Scrambled"	1	0	0	1	4	12	19	24

The majority of these failures to discriminate depth occur with the large disparity "scrambled" displays. Twenty seven of the 43 "no depth" trials reported with unequal luminance, occurred with attenuation of the non-dominant eye. "Scrambling" does not appear to influence the frequency of failures to see a depth difference for the small disparity displays.

10.11. Discussion

10.11.1. Stereoscopic Latencies for the Two Disparity Displays

"Scrambling" of the random-dot stereograms by 15% increases the stereopsis latencies to make depth discriminations by at least a factor of 2 for both the small and large disparities. These will be discussed separately below.

i) Large Disparity Displays

It would be expected that random presentation of large disparity displays with small disparity displays would preclude any development of eye movement strategies or anticipatory vergence movements occuring for fusion of the displays. Therefore, it would be expected that stereoscopic latencies with this procedure would be longer than those reported for the same displays presented in a block of 40 trials. This was not the case. The mean stereoscopic latency for the large "unscrambled" displays reported in this study was 6.78 seconds which is slightly shorter than those reported for the previous 7 subjects in chapter 9, Part B with a mean of 8.15 seconds. Subjects in chapter 9, Part A (N = 8) who had participated in the large disparity experiment first had a mean stereopsis latency of 6.87 seconds.

However, "scrambling" of these displays did increase the latencies significantly suggesting "scrambling" influences the vergence system as well as the fusional process. An increase in the ambiguity of the two displays as to the correct fusional match disrupts the monitoring of the disparity information required for vergence control. Correction of vergence errors during saccades or vergence shifts may not occur resulting in an increase in the frequency of the loss of fusion and partial fusion. Errors occurred on 26% of the large disparity "scrambled" trials together with 18% of the failures to report depth. This suggests that the hysteresis effect (Fender and Julesz, 1967) may be weakened if correlation between the two stereo fields is reduced. Horizontal misalignment of the fused areas during vergence shifts may quickly destroy fusion.

In this study latencies with the "scrambled" displays were greater than those reported in chapter 10, Part A. This may suggest that presentation of a block of trials showing large disparity "scrambled" displays results in possible practice or learning effects for fusion of these displays thereby reducing the viewing time required to see depth. This learning/practice effect may take the form of a reduced frequency of saccadic movements, or scanning movements across the displays that may occur in order to identify the extent of the disparate area and to clarify the shape in depth. The difference in the percentages of errors and failures to perceive depth reported in Part A and in this experiment lend support to this view. Alternatively the results may reflect the lack of experience or practice of these subjects at viewing random-dot stereograms.

ii) Small Disparity Displays

The mean stereoscopic latencies to perceive depth with the "scrambled" and "unscrambled" displays are 6.88 and 3.37 seconds respectively.

These are not markedly different from the mean latencies reported for seven subjects for the equivalent "scrambled" displays with a mean of 5.69 (see Part A) and "unscrambled", with a mean of 3.24 seconds (see chapter 9, Part B) that were presented as a block of 40 trials. This suggests that practice effects that may occur with successive presentation of the same disparity values and influence viewing times to see depth are not associated with viewing small disparity displays. Practice effects and strategies for fusion appear to be a feature of the large disparity discrimination procedure where eye movements are required.

More errors in depth judgements were made with the "scrambled" small disparity displays. Conjugate eye movements may have been made over the displays to inspect the clarity or form of the disparate areas and even with 8/12' of arc disparities it is possible that fusion may have been lost resulting in only partial fusion. This may have been more frequent with random presentations as on some trials the disparate areas would have appeared as well defined squares ("unscrambled"). Alternatively, the increase in errors in this experiment may again reflect the inexperience of these subjects at viewing random-dot stereograms.

10.11.2. Unequal Luminance of the Displays and Measures of Ocular Asymmetry

The results in this experiment support the hypothesis that the ocular asymmetry measures based on unequal luminance of the displays reported in previous chapters are a feature of the large disparity displays and not an artefact of particular viewing strategies.

i) Large Disparate Displays

The results from the large disparate "scrambled" and "unscrambled" trials mirror those reported for the equivalent displays reported with seven subjects in chapters 9, Part B and Part A of this chapter, latencies were significantly longer for the two conditions of unequal luminance relative to the two conditions of equal luminance.

The mean degree of asymmetry was 0.16 and 0.15 for "unscrambled" and "scrambled" displays respectively, and the range of these scores were greater for the latter type of display. No rivalry measures were collected from this group of subjects for comparison with these measures.

A random presentation sequence of large disparity "unscrambled" displays does not result in measures of asymmetry that are different from the measures derived from the same displays but presented in a block of 40 trials for the same group of subjects. Eight subjects including some from this experiment participated in 40 trials of the depth discrimination task with large "unscrambled" displays, and participated 6 months later in the same task with the same displays but presented in a random sequence over 64 trials (ie with three other types of displays; large "scrambled", small disparate "scrambled" and "unscrambled"). The asymmetry measures derived from the large "unscrambled" disparity display trials from the two procedures had a correlation coefficient of r = 0.64, which is significant at the 5% level (1-tailed test). Therefore, a random sequence of display presentation does not interact with the effects of ocular asymmetry. (These scores together with the small disparity "unscrambled" measures of ocular asymmetry are shown in Table 10.11F i., Appendix F).

ii) Small Disparity Displays

Despite the increase in stereoscopic latencies with small disparity "scrambled" displays, conditions of selective attenuation had no influence on the viewing times to make a depth judgement. This confirms previous findings for other groups of subjects (see chapter 9).

The ocular asymmetry measures were of a smaller range than those recorded for the large disparate displays and had a smaller mean degree of asymmetry. It is possible that these measures of asymmetry reflect experimental variation in the latencies and not a true asymmetry in the eyes. (The failure to find a relationship between the measures of ocular asymmetry derived from two small "unscrambled" dispar t displays experiments separated by an interval of 6 months for the eight subjects reported above support this and shown are shown in Table 10.11F ii., Appendix F.).

10.12. Summary of Chapter 10, Parts A and B.

In Part A, stereoscopic latencies were increased for depth discriminations using "scrambled" random-dot stereograms with large and small disparity displays. The increase in latencies for the small disparity displays above the "floor" level did not result in differential response times for the conditions of selective attenuation. Results from both experiments replicated previous findings; latencies were overall longer for the large disparity displays and also for the conditions of unequal attenuation of these same displays, conditions of selective attenuation did not influence response times for the small disparity displays.

The mean degree of ocular asymmetry derived from the large disparity discrimination experiment was greater than that found for the equivalent "unscrambled" displays. There was a weak relationship between these measures and the binocular rivalry measures of ocular asymmetry. The small disparity discrimination measures had a small mean degree value and were unrelated to the binocular rivalry measures.

The experiment reported in Part B formed a control for the effects of viewing strategies on response times for the large and small disparity displays under the conditions of selective attenuation. Twenty subjects naive as to viewing stereograms participated in a random sequence of trials of "scrambled" and "unscrambled", large and small disparity displays. Results replicated the above findings: selective attenuation differentially influenced response times for the large disparity displays only. How ever, there was an increased percentage of errors and failures to detect depth with the large disparity stereograms using this procedure of presentation.

The ocular asymmetry measures were again greater for the large disparity displays , "scrambled" and "unscrambled" although no comparisons were made with binocular rivalry measures.

It is concluded from the experiments in chapter 10 that the measures of ocular asymmetry derived from the large disparity depth discrimination experiments are associated with vergence eye movements and the differential results for the conditions of selective attenuation between the large and small disparity displays reflect this. The results are not due to viewing strategies possibly developed with presentation of the same disparity displays over successive trials.

CHAPTER 11

Tachistoscopic Presentation of Small Disparity Random-dot Stereograms: Depth Discrimination Measures of Ocular Asymmetry using Selective Attenuation.

11.1. Introduction

Measures of ocular asymmetry have been reported in the previous chapters based on latencies to make a depth discrimination in random-dot stereograms under conditions of selective attenuation of the displays to the two eyes. This measure gave both the direction and degree of the asymmetry and was reported for both large and small disparity displays. Measures derived from the large disparity discrimination task correlated significantly with ocular asymmetry measures derived from the binocular rivalry task for 15 subjects. However, latencies for the conditions of selective attenuation were not found to be significantly different with the small disparity displays, and the measures of ocular asymmetry were not related to the binocular rivalry measures.

Four experiments have shown that latencies to discriminate depth using small disparate displays are not influenced by selective attenuation, and ocular asymmetry effects are not a feature of viewing small disparity displays. However, latencies to make depth discriminations with the small disparity displays were in the order of seconds suggesting that vergence movements may still be occuring (even though there are no ocular asymmetries). Therefore, a direct test that asymmetries of the vergence system are not involved would be to use tachistoscopic presentation of the small disparate stimuli.

The experiment reported in this chapter was designed to control for the influence of vergence movements in the depth discrimination measures of ocular asymmetry. Random-dot stereograms with disparate areas of 8/12' of arc were tachistoscopically presented under the four conditions of selective attenuation. Exposure durations were chosen that excluded the initiation of vergence movements. Vergence latencies have been taken to be about 160 m secs (Westheimer and Mitchell, 1969), therefore, exposure durations of the displays were chosen below this value. Successful depth perception with tachistoscopic presentation of random-dot stereograms has been reported in other studies (Julesz, 1963b, 1964; Julesz and Chang, 1976; Mayhew and Frisby, 1979).

Mayhew and Frisby (1979) in a study using a similar procedure to the one to be reported here, found that stereograms with two disparate squares with a disparity difference of 2.6' of arc could be successfully fused and the depth discriminated with brief presentation times of 60 msecs. Depth up to baseline disparities of 12-15' of arc were discriminated at threshold exposure durations of 60 msecs, and therefore do not involve the vergence system. Both the relative difference in disparity of the squares and the overall level of the baseline disparity could be discriminated.

The experiment reported here involves tachistoscopic presentation of random-dot stereograms using a two-alternative forced-choice procedure. Exposure durations under 150 msecs were chosen independently for each subject in a pilot study to establish a 70% correct baseline level. It was expected that the percentage of correct depth discriminations would vary from this value with the conditions of selective attenuation. Exposure durations were not reduced below 60 msecs although several subjects were found to have 100% or almost 100% correct baselines at these exposures. The displays for these subjects were "scrambled" between 5 and 30% until the 70% baseline was achieved. A similar procedure was reported by Julesz (1971, page 275) although the aim was to develop a criterion to grade stereoscopic ability.

When the exposure durations and percent "scrambling" of the displays had been established for each subject, they participated in the experiment to discriminate depth under the four conditions of selective attenuation, to test the following hypotheses:

1) That the frequency of correct depth discriminations would be differentially reduced from the 70% baseline under the conditions of selective attenuation.

2) That a measure of ocular asymmetry based on the frequencies of correct depth discriminations would be derived from the two unequal attenuation conditions. This measure would be based on a similar formula to that reported in the previous experiments based on

stereoscopic latencies. The assumption here is that a greater number of correct depth discriminations would be made with the dominant eye attenuated relative to the condition of attenuation of the non-dominant eye.

And in addition,

3) A comparison of this measure of ocular asymmetry with the binocular rivalry measures of asymmetry.

11.2. Method

11.2.1. Subjects

Nine subjects participated in this experiment, all were members of St Andrews University. Six subjects had participated in some of the previous experiments on binocular rivalry and the depth discrimination experiments. The three new subjects participated in two sessions on binocular rivalry (using the 4 response procedure) and four experiments on depth discriminations with two disparity values and two types of display; "scrambled" and "unscrambled". The measures of ocular asymmetry for all nine subjects are given in Table 11.1G in Appendix G.

11.2.2. Apparatus

A modified stereoscope arrangement was used as outlined on page 119, see Figure 9.1. The random-dot stereograms were generated by the computer and displayed on the CRT screens. The apparatus was essentially the same as that reported in chapter 9 apart from the following modifications:

1) The amplitude of the z-signals were electronically controlled via the computer interface that sent a negative DC signal to the z-inputs of each scope independently.

2) Two switch keys were provided for the subject; one to indicate that the "upper" square had the greatest depth and the other to indicate that the "lower" square had the greatest depth.

11.2.3. The Stereograms

The stimuli were generated on the CRT scope screens by the computer, NOVA 1220 and each stereo field was composed of 64x64 dots subtending a visual angle of $4^{o}x4^{o}$. The two disparate square areas subtended a visual angle of 1^{o} 8'x1^{o} 8', one above and one below the fixation point.

The fused stereogram had a space average luminance of 7 cdm-2 and the space average luminance of the surround was 0.9 cdm-2.

The two disparate areas had a crossed disparity of 8 and 12' of arc, the square with the greater disparity was randomly assigned to either the top or bottom square throughout the trials. The subjects' task was a two-alternative forced-choice and a 70% correct baseline was used to establish the threshold exposure durations for the depth discriminations. Durations below 60 msecs were not used and it was found that some subjects were responding with 100% correct discriminations at these exposures. To achieve a 70% correct performance, "scrambling" was introduced into the displays for these subjects. The amount of "scrambling" was specified at the start of the experiment and was matched to the subjects' ability to discriminate depth at the 70% level. "Scrambling" was in the range 5-30% and was constant for that specified level for that subject throughout the experiment.

11.2.4. Procedure

Subjects were given a total of 280 trials, administered in 7 blocks of 40 trials. There were four experimental conditions of attenuation as follows:

Condition 1: Neither scope attenuated by 1 log unit
Condition 2: Both scopes attenuated by 1 log unit
Condition 3: Left scope attenuated by 1 log unit
Condition 4: Right scope attenuated by 1 log unit

There were 10 trials for each condition within the 40 trial block and these were randomly assigned over the 40 trials, making a total of 70 trials for each condition. Three blocks of 40 trials were given on one day and four on another.

Subjects were asked to fixate the central fixation dot throughout the experimental session. A 1 second tone preceded the presentation of the stereogram. The exposure duration of the stereogram was individually matched to the subject's ability to discriminate depth. Subjects were required to discriminate which square appeared to protrude the farthest. They indicated their response by pressing one of the two switch keys. There was an intertrial interval of 3 seconds.

The task was a two alternative forced-choice. Subjects were asked to respond even if they were unsure of which square had the greatest depth. All subjects participated in a pilot study to establish the exposure duration to achieve a 70% correct performance level. This was carried out with neither scope attenuated. The level of "scrambling" was also established if required. Table 11.1 shows the duration and percent "scrambling" for each subject for this criterion baseline of 70%.

Table 11.1 Threshold Exposure Durations (mseconds) and Percent "Scrambling" for Depth Discriminations in Random-dot Stereograms.

Subjects:	Exposure Duration	Percent "Scrambling"
SC	100	5
EB	70	18
SM	60	25
SK	65	20
EM	100	0
SW	60	30
DM	100	0
EC	65	20
AL	65	25

All 280 trials for each subject were run with the specified exposure durations and percentage of "scrambling" as above. The number of correct depth discriminations were recorded over the trials and calculated for each experimental condition.

11.3. Results

11.3.1. Percentage of Correct Depth Discriminations for Conditions of Selective Attenuation

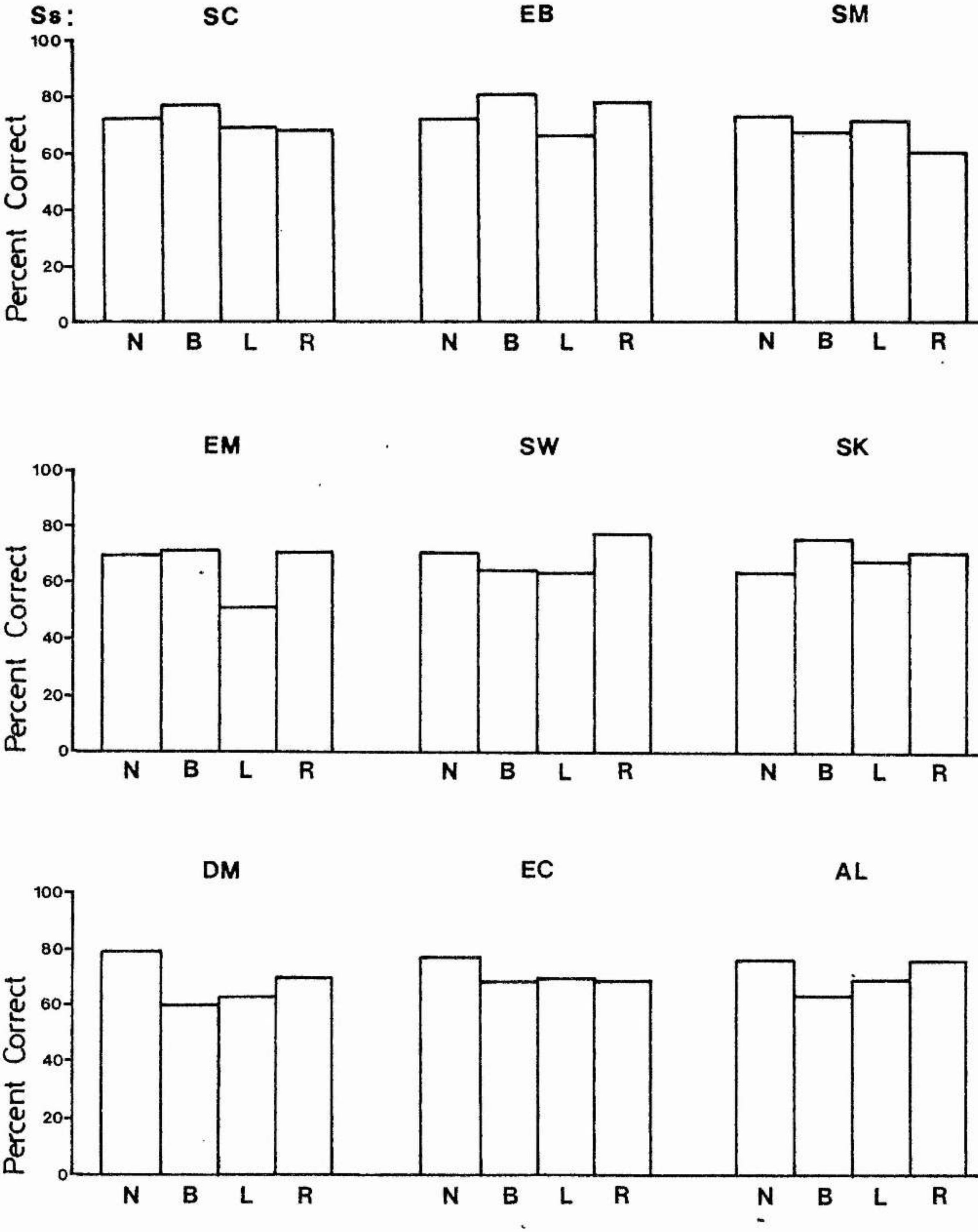
The number of correct depth discriminations under each of the four conditions for each subject is shown in Table 11.2. Fig 11.1 shows this data as histograms for percent correct.

Table 11.2 Frequency of Correct Depth Discriminations Between Two Squares (8'/12' of arc disparity) under Four Conditions of Selective Attenuation.

Conditions:	Neither display Attenuated	Both displays Attenuated	Left display Attenuated	Right display Attenuated
Subjects:				
SC	51	54	49	46
EB	50	56	46	54
SM	51	47	50	42
SK	44	53	47	49
EM	48	50	36	48
SW	49	45	44	54
DM	56	42	44	49
EC	55	48	49	48
AL	53	45	48	53

As can be seen from the histograms that there is very little variation in the frequency of correct responses under the four conditions of selective attenuation for each subject. Chi squared tests were carried out on the frequencies of correct and incorrect responses out of the total of 70 trials under each of the four conditions of selective attenuation for each subject (Table 11.2G in Appendix G lists the chi-squared values for each subject). None of the chi-squared tests were significant. These results indicate that the conditions of selective attenuation have no influence on the frequency of correct responses.

Fig 11.1 Histograms of the Percentage of Correct Depth Discriminations made under Four Conditions of Selective Attenuation.



N - Neither Display Attenuated

B - Both Displays Attenuated

L - Left Display Attenuated

R - Right Display Attenuated

11.3.2. Measures of Ocular Asymmetry

Measures of ocular asymmetry were derived from the number of correct depth discriminations under the two unequal luminance conditions using the following formula:

$$\text{Asymmetry score} = \frac{LE - RE}{LE + RE}$$

LE = number of correct depth discriminations with the left attenuated.

RE = number of correct depth discriminations with the right attenuated.

It is assumed that a greater number of correct responses would be made with attenuation of the dominant eye relative to the attenuated condition of the non-dominant eye. A negative value indicates a right ocular asymmetry, a positive value indicates a left ocular asymmetry.

Table 11.3 shows the asymmetry scores indicating direction and degree for each subject from this procedure together with the binocular rivalry measures of ocular asymmetry for each subject.

Table 11.3 Ocular Asymmetry Scores

Subjects:	8/12' of arc disparity	Binocular rivalry experiment
SC	+0.01	-0.10
EB	-0.08	-0.008
SM	+0.08	+0.05
SK	-0.02	-0.02
EM	-0.14	-0.26
SW	-0.10	+0.15
DM	-0.05	-0.22
EC	+0.003	-0.23
AL	-0.05	-0.48

Only three subjects have left ocular asymmetries. The mean degree of asymmetry is 0.06 which is small relative to the degree of asymmetry derived from the stereoscopic latencies for depth discriminations reported in previous chapters.

11.3.3. Measures of Ocular Asymmetry derived from the T-scope Experiment and the Binocular Rivalry Experiment

All these subjects had participated in at least one session of binocular rivalry recording from which binocular rivalry measures of ocular asymmetry were calculated (the four response procedure was used) and are shown in the far right column of Table 11.3. There was no relationship between these two scores (r=0.16, not significant).

11.3.4. Measures of Ocular Asymmetry derived from the T-scope Experiment and the Depth Discrimination Measures of Ocular Asymmetry(1)

A weak relationship was found between these measures of ocular asymmetry and the small disparity discrimination measures for the "unscrambled" displays (r=0.38, not significant) but there was a significant relationship between the present results and the small "scrambled" displays, r=0.61, p<0.05, (1-tailed test).

Five out of the nine subjects had a sighting eye that was also the dominant eye as defined in this experiment.

11.4. Discussion

Tachistoscopic presentation of random-dot stereograms with exposure durations of 100 msec or less resulted in successful discriminations of depth (this supports the findings of Mayhew and Frisby, 1979). The involvement of fusional vergence movements in these measures can therefore be excluded (Westheimer and Mitchell, 1969).

(1)There is no reason to expect a relationship between the measures of ocular asymmetry reported in this experiment and the large disparity depth discrimination measures given the assumed involvement of vergence eye movements. There was no significant relationship found between the measures of ocular asymmetry as measured with the T-scope presentation procedure using small disparities and the large disparity measures based on stereoscopic latencies for "unscrambled" (r=0.58, not significant, 2-tailed test) and "scrambled" displays (r=0.24, not significant, 2-tailed test).

The results also show that for subjects with good stereopsis even a high percentage of "scrambling" of the display does not destroy this ability to discriminate depth. Six subjects EB, SM, SK, SW, EC and AL had exposure durations under 70 msecs despite 18-30% of the dots of the displays being "scrambled". This high level of "scrambling" was required to impair the ability to discriminate depth to achieve the 70% correct baseline in the pilot study.

However, selective attenuation of the displays did not influence the frequency of correct depth discriminations. The hypothesis was not confirmed. Unequal luminance of the two displays did not increase the frequency of incorrect depth judgements relative to the frequencies reported for conditions of equal luminance. Despite a more sensitive measure of the effects of selective attenuation on the ability to discriminate depth stereopsis with small disparities is relatively unaffected. These results using a two alternative forced-choice procedure confirm the previous findings reported in chapters 9 and 10 using stereoscopic latencies. Selective attenuation did not differentially affect the stereoscopic latencies for depth discriminations using these small disparity levels.

Measures of ocular asymmetry were derived from the frequency of correct depth discriminations for the two conditions of unequal attenuation. The mean degree of asymmetry was very small (0.06) as was the range of scores; -0.14 to +0.08. These measures of asymmetry were not related to the binocular rivalry measures.

However, these measures of asymmetry were weakly related to the small disparity measures of asymmetry based on latencies to discriminate depth (this was significant for the "scrambled" displays). The mean degree of asymmetry for each of these latter measures were also small (see Appendix G for individual scores). These findings indicate that stereopsis with small disparities is relatively unaffected by modifications of the displays to the two eyes (ie. by a 1 log unit attenuation). Therefore it can be concluded that ocular asymmetries are a feature of the vergence system. Measures of ocular asymmetry based on stereoscopic latencies for small disparity displays reported in previous chapters may reflect experimental variation in latencies over trials. The measures of asymmetry derived from the two experiments with "unscrambled" small disparities separated by an interval of at least 6 months (reported at the end of the last chapter) were unrelated and supports this conclusion (see Appendix F, Table 10.11F, ii). Measures of ocular asymmetry based on the two large disparity "unscrambled" experiments separated by the same interval were found to be related.

11.5. Summary of Chapter 11

The experiment in this chapter was designed as a control for the involvement of vergence eye movements in the measures of ocular asymmetry derived from small disparity displays reported in chapter 9 and 10.

Results from this experiment showed that ocular asymmetries are not a feature of depth discrimination procedures when vergence eye movements are not involved. Successful depth discriminations were made between disparate areas (8/12' of arc) in random-dot stereograms with exposure durations of between 60 and 100 msecs and therefore without the aid of vergence movements, (Westheimer and Mitchell, 1969). "Scrambling" of the displays reduced the ability of some subjects to make correct depth judgements from 100 to 70% at 60 msec exposures.

Selective attenuation of the displays to the two eyes did not influence the reports of correct depth discriminations and indicates that the stereopsis/fusional process is insensitive to modifications of the displays to the two eyes. Measures of ocular asymmetry derived from the two conditions of unequal attenuation were small in degree, had a small range and were unrelated to the binocular rivalry measures.

The results in this chapter using T-scope presentations that prevent vergence eye movement execution indicate that the measures of ocular asymmetry are a feature of large disparity processing as with the displays used in chapters 9 and 10 and involve vergence movements or the vergence control system. The asymmetry measures reported with small disparity displays may reflect experimental noise (however this is not to say that even at these small disparities of 8 to 16' of arc and with free viewing, vergence movements did not occur).

11.6. Conclusions of Part III

Measures of ocular asymmetry have been reported in Part III based on conditions of selective attenuation of the displays to the two eyes in a depth discrimination task. This measure gives both the degree and direction of the asymmetry along a fixed continuum. However, this measure was found for large disparity discriminations only indicating that the vergence system is involved. This was further supported by a control experiment (chapter 11) in which small disparate stereograms were presented tachistoscopically at exposure durations that preclude vergence eye movements. No effect of selective attenuation on the percentage of correct discriminations of depth was found.

These measures of ocular asymmetry were related to the measures of ocular asymmetry derived from the binocular rivalry procedure (for 15 subjects). Thus, asymmetries in binocular vision derived from a competitive viewing situation ie. rivalry are related to asymmetries derived from a situation requiring a co-operative interaction between the eyes ie. with stereoscopic viewing.

PART IV

INTEROCULAR TRANSFER MEASURES OF OCULAR ASYMMETRY

CHAPTER 12

Interocular Transfer Measures of Ocular Asymmetry

12.1. Introduction

Two measures of ocular asymmetry have been reported so far in this thesis. One measure was based on binocular rivalry recordings and the other was derived from a stereoscopic discrimination task with selective attenuation of the two displays. The two measures were significantly correlated although the binocular rivalry measures of ocular asymmetry were small and centred about the mean.

An explanation was proposed for the asymmetric effects of attenuation which was based on the need for fusional vergence movements with large disparity stereograms. It is possible that the asymmetry measures reflect asymmetries in either the binocular processes that subserve the vergence system or the oculomotor system itself. Binocular interaction or cooperativity are involved with cyclopean stimulation using random-dot stereograms, and therefore the asymmetries found with this procedure can be assumed to be in the binocular system.

The aim of the work described in this thesis has been to derive asymmetry measures from a variety of situations involving binocular viewing. The experiments in this section were designed to investigate possible asymmetries in binocular vision using the psychophysical technique of interocular transfer and to derive a measure of ocular asymmetry.

12.2. Interocular Transfer of the Spatial Frequency Shift

Prolonged exposure to a visual stimulus often results in adaptation or reduced sensitivity to that stimulus dimension and also to stimuli that are similar to the adapting stimulus. This technique of selectively adapting the visual system to different stimuli has been used to investigate the extraction of particular features from the optical array (Blakemore and Sutton, 1969). Investigation of spatial frequency (SF) analysis in the visual system has been carried out using selective adaptation to different spatial frequency gratings (Blakemore and

Sutton, 1969). Prolonged exposure to a high contrast grating results in a perceived shift in the frequency of a subsequently viewed grating of a slightly different spatial frequency from the adapting frequency. This effect is known as the spatial frequency shift (Blakemore and Sutton, 1969; Blakemore, Nachmias and Sutton, 1970). The existence of spatial frequency tuned channels have been inferred from these and other related studies (Blakemore and Campbell, 1969; Blakemore and Sutton, 1969). The channel model has been used to explain the spatial frequency shift as follows: adapting to high contrast grating is assumed to depress the sensitivity of channels tuned to spatial frequencies close to the spatial frequency of the adapting grating. Presentation of a test stimulus of a slightly different spatial frequency produces a reduced response from these channels. However, channels tuned to spatial frequencies further from the adapting stimulus frequency are assumed not to be affected and the peak sensitivity is shifted towards those unadapted channels which are assumed to be responsible for the perceived shift in spatial frequency (Blakemore and Sutton, 1969).

Selective adaptation has been claimed to induce fatigue in a set or population of neurones selectively sensitive to the stimulus features which results from prolonged excitation during the inspection phase (Sutherland, 1961). Other researchers have claimed that adaptation is the recovery from inhibition that occurs between channels (Dealy and Tolhurst, 1974). This latter view is supported by evidence that aftereffects can be generated to their maximum extent in a matter of milleseconds reflecting a short-term mechanism (Sekuler and Littlejohn, 1974). The mechanism underlying adaptation in the visual system is however, not the subject of study here. This study is concerned with the magnitude of the spatial frequency shift generated under different viewing conditions.

Blakemore and Sutton (1969) reported that the spatial frequency shift transferred from one eye to another. Adapting one eye resulted in a spatial frequency shift of the test grating viewed by the other. This condition is known as the interocular transfer condition. Interocular transfer of visual aftereffects have been reported as being between 50 and 60% of the magnitude of the aftereffect measured in the monocular condition (Moulden, 1980). The spatial frequency shift has been reported to transfer at a magnitude 50% of that reported for the monocular adapt and test condition (Blakemore, Nachmias and Sutton, 1970).

The transfer of the aftereffect is assumed to reflect binocular processes. Evidence for the involvement of binocular channels or processes comes from three sources: i) The magnitude of a visual aftereffect is not reduced if the adapting eye is pressure blinded during testing of the other eye (Barlow and Brindley, 1963; Blake and Fox, 1972; Meyer, 1974). Pressure blinding prevents the neural signals from the retina contributing to the transferred aftereffect. ii) Transfer of visual aftereffects have been reported to be reduced in stereoblind individuals who have had a history of early strabismus (Movshon, Chambers and Blakemore, 1972; Mitchell and Ware, 1974; Lema and Blake, 1977). These stereoblind individuals are assumed to have a reduced complement of binocular neurones relative to normal binocular individuals who possess stereopsis (Bank, Aslin and Letson, 1975; Hohmann and Creutzfeldt, 1975). iii) Interocular transfer is both spatial frequency specific and orientationally selective. Spatial frequency adaptation has been reported in single cells of the cat striate cortex and not in the Lateral Geniculate Nucleus (Movshon and Lennie, 1979) and orientation selectivity would not be expected until outputs from several retinal ganglion cells with specific orientational selectivity had been combined at higher centres ie. at binocular sites (Hubel and Wiesel, 1962).

12.3. Asymmetry in Transfer of Visual Aftereffects

Several different visual aftereffects have been reported to transfer asymmetrically between the eyes eg. adapting the left (right) eye and testing on the right (left) results in a greater aftereffect relative to the condition of adapt right (left) and test on the left (right). The direction of maximal transfer has been associated with sighting dominance, transfer being greater from the sighting dominant to the non-dominant eye relative to transfer from the sighting non-dominant to the dominant eye (Movshon, Chambers and Blakemore, 1972; Mitchell, Reardon and Muir, 1975; Wade, 1976a; Maraini and Porta, 1978; Bjorklund and Magnussen, 1981). Suprathreshold stimuli were used in these studies apart from the latter study of Bjorkland and Magnussen (1981) who reported a 7% difference in transfer magnitude in contrast threshold elevation between the direction from the sighting to the non-sighting eye relative to the reverse direction. Movshon et al (1972) reported that adapting the sighting eye and testing on the non-sighting eye resulted in greater transfer relative to adapting the non-sighting eye and testing on the sighting eye. They (1972) concluded that the sighting dominant eye has a greater influence on the visual cortex.

The magnitude of the transferred aftereffect has in some of the studies been expressed as a percentage of the aftereffect magnitude measured in the monocular viewing condition. The monocular viewing condition chosen is that of the tested eye in the transfer condition as shown below:

$$\text{i) Transfer (\%) from left to right} = \frac{\text{Adapt LE} \rightarrow \text{Test RE}}{\text{Adapt RE} \rightarrow \text{Test RE}} \times 100$$

or,

$$\text{ii) Transfer (\%) from right to left} = \frac{\text{Adapt RE} \rightarrow \text{Test LE}}{\text{Adapt LE} \rightarrow \text{Test LE}} \times 100$$

Maraini and Porta (1978) however, expressed the amount of tansfer as a percentage of the aftereffect magnitude found in the monocular adapt/test condition for the adapted eye as shown below:

$$\text{Transfer (\%) from right to left} = \frac{\text{Adapt RE} \rightarrow \text{Test LE}}{\text{Adapt RE} \rightarrow \text{Test RE}} \times 100$$

No reason for this difference in procedure was offered. However, the magnitudes of the aftereffects for the two monocular conditions of adapt/test have been reported to be equal and sometimes to be slightly smaller on the sighting dominant eye (Movshon, Chambers and Blakemore 1972; Mitchell and Ware 1974).

Wade (1976a) reported a non-significant relationship between the direction of maximum transfer and the sighting dominant eye, it being slightly greater from the sighting dominant eye to the non-dominant eye which was also mirrored in the rivalry dominance results. Not all studies have reported an asymmetry in transfer. Blake, Overton and Lema-Stern (1981) reported no difference in the two directions of transfer of the contrast threshold elevation although it is not certain if their subjects showed any dominance effects in the two eyes. In contrast, 8 out of 10 subjects were reported to show greater transfer of the tilt aftereffect from the non-sighting to the sighting eye (Wade and Wenderoth 1978). Also Heeley (1979) reported a greater transfer of the spatial frequency shift from the non-preferred eye (sighting eye) to the preferred eye relative to the reverse direction. This differential diminished at high adapting contrasts. It is not at all clear what the relationship is between the direction of maximum transfer and the sighting dominant eye.

Transfer of visual aftereffects have also been reported in amblyopic subjects. Hess (1978) reported almost similar amounts of transfer from the amblyopic to the non-amblyopic eye as in the reverse direction (67% and 64% respectively). Anderson, Movshon and Timney (1980) reported transfer of the threshold elevation of contrast to be greater from the non-amblyopic to amblyopic eyes but there was substantial transfer in the opposite direction. Transfer of visual aftereffects does not appear to be associated with visual loss as found in amblyopia (Keck and Price, 1982). Movshon et al (1972) concluded from their results that the interocular transfer paradigm can be used as a further measure of eye dominance (ie. sighting dominance).

12.4. Methodology Adopted in this Study

A nulling technique was used to measure the spatial frequency shift. Subjects adapted to two gratings that had a spatial frequency ratio of approximately 2:1. After adaptation, two test gratings were displayed on the same display screen which had equivalent spatial frequencies intermediate to the spatial frequencies of the adapting patterns. The two test gratings appeared shifted in spatial frequency, one appeared higher and the other lower in spatial frequency relative to their true spatial frequencies (Blakemore and Sutton, 1969, op. cit.). Subjects were required to null the spatial frequency shift aftereffect by introducing a physical spatial frequency difference in the test gratings until they appeared to be matched. The spatial frequency difference at the null point was used as a measure of the spatial frequency shift.

The method of equivalent occlusion was used (Lehmkuhle and Fox, 1976a). The eye unadapted in the inspection phase and the eye not tested during the test phase viewed a homogeneous background of the same space-average luminance as the grating display. Other studies investigating transfer effects have used opaque occlusion (Mitchell and Ware, 1974; Ware and Mitchell, 1974; Mitchell, Reardon and Muir, 1975; Hess 1978). Lehmkuhle and Fox (1976a) reported that the magnitudes of transferred aftereffects were increased by up to 20-25% if equivalent occlusion was used.

12.5. The Aims of This Study

The magnitude of the spatial frequency shift was investigated under five conditions of adaptation and test: two conditions of adapt and test in the same eye (monocular viewing), one condition of adapt and test in both eyes (binocular) and two conditions of adapt one eye, test in the other (transfer). The experiment was designed to test the following hypotheses:

1) That the magnitude of the spatial frequency shift in the binocular viewing condition would be similar to the magnitude in the two monocular conditions of adapt and test. (The results will be compared to the results predicted from the models of interocular transfer discussed in chapter 14).

2) That the magnitude of the transferred spatial frequency shift would be less than the magnitude measured with monocular viewing. (Transferred aftereffects have been reported to be between 50 and 60% of the monocular condition (Moulden, 1980)).

3) That the magnitude of the spatial frequency shift would be larger when generated in the dominant eye (ie. adapt and test the same eye) relative to that in the non-dominant eye. Dominance is defined by i) the large disparity depth discrimination measures, ii) the binocular rivalry measures and iii) sighting dominance.

4) That the direction of maximum transfer would be from dominant to the non-dominant eye (ie. adapt dominant eye, test the non-dominant eye) relative to the reverse direction. Dominance is

defined as above in i), ii) and iii).

And in addition,

5) That a measure of ocular asymmetry can be derived from the two transfer conditions that may differ in degree and this measure can be compared to other measures of ocular asymmetry derived from i) the large disparity depth discrimination procedure and ii) the binocular rivalry experiment with real images.

6) That the mean percentage of interocular transfer of the spatial frequency shift can be used as in an "index of binocularity" as measured by stereo-thresholds. Stereo-thresholds are measured in chapter 13 and discussed in relation to the transfer magnitudes.

12.6. Method

12.6.1. Subjects

Eight subjects from the University of St Andrews participated in the experiment. All subjects had participated in previous experiments on a) the depth discrimination procedures (as reported in chapter 9) for both the large and small disparity stereograms, (the stereoscopic latencies for each subject from the two experiments are shown in Appendix H, Tables 12.1H and 12.2H) b) the binocular rivalry experiment and c) the sighting test (point test). Table 12.1 below shows the measures of ocular asymmetry and sighting dominant eye for each subject derived from the above experiments.

12.6.2. Apparatus

Subjects viewed the stimulus displays 57 cms away in a modified stereoscope arrangement (see Fig 9.1, page 120 and page 119 for details of the apparatus). Vertical square wave gratings were generated electronically on two CRT Tektronix 604 oscilloscopes. Each display screen subtended a visual angle of $13.5^{\circ} \times 10^{\circ}$. Each screen was divided horizontally into an upper and lower half by a black strip of card, 0.65 cms wide.

Table 12.1 Ocular Asymmetry Measures and Sighting Dominance

Subjects:	a)Binocular Rivalry Procedure	b)Depth Discrimination Procedure i.Large Disparity	ii.Small Disparity	c)Sighting Dominance
SM	0.050	0.300	0.001	LE
DM	-0.220	-0.142	-0.054	LE
PR	-0.002	-0.079	-0.413	LE
PC	-0.136	-0.405	-0.161	RE
EM	-0.260	-0.370	-0.040	LE
EB	-0.008	-0.090	-0.430	LE
SW	0.147	0.300	-0.120	RE
SK	-0.017	0.410	-0.130	RE

The gratings were generated using the Campbell and Green (1965) method. The line frequency was 200 KHz. The signal to the vertical axis was shifted by a preset potentiometer so that each grating filled half the screen. A split screen display was formed by shifting the complete raster scan display vertically at 100 Hz to generate the separate grating patterns. The square wave from the signal generator drove the z-signal and synchronised the time base so that a bar appeared at the extreme edge of the screen. In order to produce different spatial frequencies for the upper and lower gratings the z-signal was monitored by a voltage control frequency unit, the input to which could be altered by a potentiometer so that the upper and lower frequency ratio could be any value in the range 2 : 1 to 1 : 1. (see Appendix H for the graph of potentiometer reading x ratio of the two gratings).

The top and bottom gratings could be interchanged and the spatial frequency and contrast of the gratings could be altered independently without affecting the space-average luminance of the displays. The average space luminance was 3.5 cdm-2. The contrast of the square wave grating was 0.7 (1).

The spatial frequency of the adapting gratings were 3c/o and 5.6c/o giving a ratio of 1 to 1.9. The spatial frequency of the test grating was 4.28 c/o for both the upper and lower gratings.

The conditions of viewing for the adaptation and test gratings were controlled on-line by the computer Nova 1220.

12.6.3. Procedure

The spatial frequency shift was briefly explained to each subject before they participated in a preliminary adapt-test phase.

At the beginning of each experimental session, subjects were given an initial three minutes of adaptation followed by the test/re-adapt sequence of 1 second and 10 seconds respectively. Subjects were required to scan their eyes back and forth along the horizontal black strip throughout the adapt and test phases. This reduced the possibility of afterimages forming (Smith, 1977).

Subjects were required to null any apparent shift in spatial frequency of the upper and lower test gratings after inspection of the adapting gratings using the 10 turn potentiometer. Each subject participated in an initial practice session on the rate of change of the ratio of the upper to the lower grating for each turn of the potentiometer. During the experimental session subjects were told to turn the potentiometer as far as it was necessary for the upper and lower test gratings to appear matched. The test grating was displayed for only 1 second, therefore subjects turned the potentiometer while the adapting gratings were displayed. The result of their action was seen in the following test phase. The test/re-adapt sequence was continued until subjects reported being satisfied with the apparent match of the upper and lower gratings. A two minute interval was given between each experimental session.

The potentiometer was read at the end of each session and converted into a ratio of the upper test to the lower test grating using the conversion graph in Appendix H.

(1)Contrast was defined by the following:

$$C = \frac{(L_{maximum}-L_{minimum})}{(L_{maximum}+L_{minimum})}.$$

There were five experimental conditions of viewing the adapting and test gratings. These were:

Conditions	Notation	Adapting Gratings	Test Gratings
1.Binocular	(LE+RE->LE+RE)	LE + RE	LE + RE
2.Monocular	(RE -> RE)	RE	RE
3.Monocular	(LE -> LE)	LE	LE
4.Transfer	(RE -> LE)	RE	LE
5.Transfer	(LE -> RE)	LE	RE

LE = presentation of the gratings to the left eye

RE = presentation of the gratings to the right eye

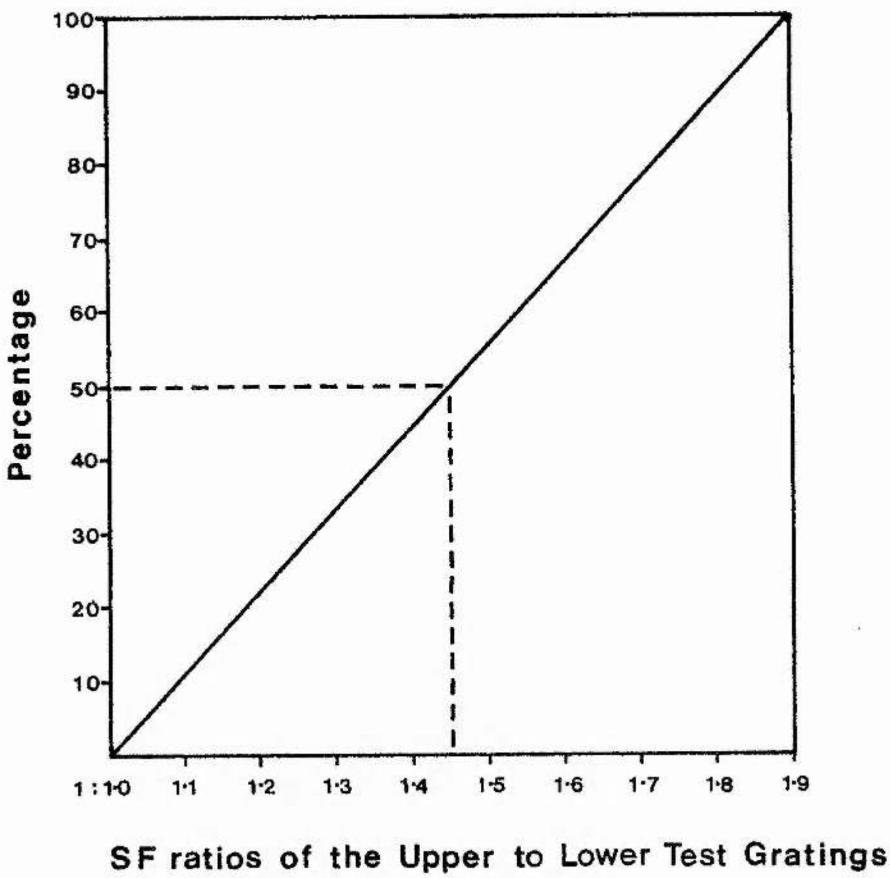
Equivalent occlusion was used in the viewing conditions of transfer and monocular viewing. The screen without the grating display was homogeneous with the equivalent space-average luminance.

There were five experimental sessions. In each session there were two adapt-test sequences for each of the five viewing conditions which were randomly presented over the 10 sequences or trials. A total of 10 readings were taken from the adapt-test sequences for each condition of viewing.

After each reading the upper and lower gratings of the adapting display were interchanged. After the initial three minutes of adaptation a further three minutes was given for each subject to make a match of the upper and lower gratings.

Each potentiometer reading was transformed into the ratio of the top to the bottom test gratings using the graph in Appendix H. This ratio (ie. the amount of physical spatial frequency shift added to null the perceived spatial frequency shift) is a proportion of the spatial frequency ratio of the adapting pair of gratings expressed as a percentage as shown in the graph below.

Graph to show the Spatial Frequency Ratio of the Test Pair of Gratings as a Proportion of the Spatial Frequency Ratio of the Adapting Gratings (%).



A setting of the two test gratings at a ratio of 1:1.45 is equivalent to a 50% spatial frequency shift of the adapting grating. A ratio of 1:1.9 is equivalent to a 100% spatial frequency shift.

12.7. Results

12.7.1. Magnitude of the Spatial Frequency Shift under the Five Conditions of Viewing

Table 12.2 shows the mean percent spatial frequency shift and standard deviations for the five experimental conditions for each subject. The two monocular conditions of viewing resulted in an overall mean aftereffect very similar to the mean overall magnitude reported in the binocular viewing condition. The two conditions of transfer show the

Table 12.2 Mean Percentage Spatial Frequency Shift and standard deviations (SD) for Five Conditions of Viewing.

	Conditions of Adapt (A) and Test (T)										4+5*
	1.Binocular		2.Monocular		3.Monocular		4.Transfer		5.Transfer		2 /2+3x100
	A	T	A	T	A	T	A	T	A	T	2
	RE+LE - RE+LE		RE - RE		LE - LE		RE - LE		LE - RE		(%)
Ss:											
SM	15.6	7.0	20.3	11.0	15.4	9.0	12.9	3.0	13.5	8.0	74.0
DM	17.8	7.0	25.2	8.0	17.9	10.0	10.9	6.0	12.0	7.0	53.0
PR	15.0	9.0	15.5	6.0	12.4	12 0	12.0	9.0	8.7	6.0	74.0
PC	14.5	8.0	23.2	15.0	27.2	14.0	17.4	16.0	13.3	9.0	61.0
EM	16.0	8.0	17.0	8.0	13.2	7.0	10.7	6.0	10.0	7.0	68.0
EB	25.9	14.0	30.0	21.0	29.3	20.0	28.9	23.0	26.7	14.0	93.0
SW	38.2	5.0	31.4	9.0	37.8	8.0	20.2	6.0	30.5	7.0	73.0
SK	21.3	8.0	22.6	8.0	27.5	10.0	8.9	3.0	9.9	5.0	37.5
Mean	20.5		23.2		22.6		15.2		15.6		66.7

* - See text for explanation.

smallest overall mean aftereffect magnitudes although this does represent 66.7% of the mean magnitude reported for the monocular conditions (see the far right column of Table 12.2).

It can be seen from Table 12.2 that there are wide individual differences in the magnitudes of the spatial frequency shifts reported (see the far right column in Table 12.2).

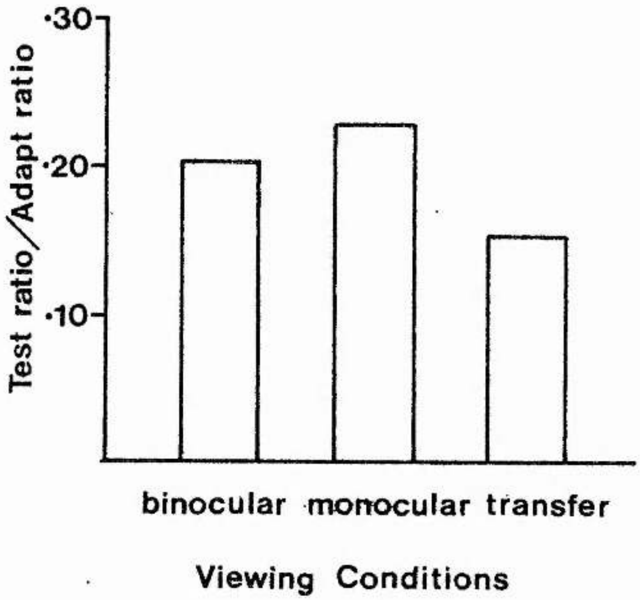
The readings were entered into a two-way analysis of variance, the factors were: conditions of viewing (5) and readings (10 sequences and readings for each condition). The five conditions of adaptation and test were significantly different ($F=7.9198$, df 4, 28 $p<0.0002$). Comparisons between the overall mean spatial frequency shifts using the Scheffe test showed that there was a non-significant difference between the monocular viewing conditions and the binocular viewing condition (the mean difference is 2.4% which is not significant). However, the two conditions of transfer had significantly lower spatial frequency shifts compared to those reported for the two monocular viewing conditions (the mean difference is 7.5% which is significant at the 5% level). Fig 12.1 shows the extent of the spatial frequency shift for the three conditions of viewing. (The summary table for the analysis of variance and the comparisons between the means are shown in the Appendix H).

12.7.2. Magnitude of the Spatial Frequency Shift in the Two Monocular Viewing Conditions and Measures of Ocular Asymmetry

It can be seen from Table 12.2 that the magnitudes of the spatial frequency shifts in the two monocular viewing conditions are not equivalent for any of the subjects. Is the spatial frequency shift greater when adaptation and testing is on the dominant eye relative to the magnitude found with adaptation and testing on the non-dominant eye? The magnitudes of the spatial frequency shift for the two monocular conditions are examined below in relation to the different measures of ocular asymmetry.

1) There was no difference in the magnitudes of the spatial frequency shifts on the dominant eye defined by the large disparity depth discrimination procedure (overall mean spatial frequency shift is

Fig 12.1 Mean Spatial Frequency Shift for Three Conditions of Viewing (averaged over subjects).



24%) compared to that on the non-dominant eye (overall mean shift is 22%), (t=1.37, df 7, not significant).

2) There was no significant difference in the magnitudes of the spatial frequency shifts on the rivalrous dominant eye (mean spatial frequency shift overall subjects is 23.4%) compared to that on the non-dominant eye (mean spatial frequency shift overall subjects is 22.4%)(t=0.55, df 7, not significant).

3) The magnitude of the spatial frequency shift is less on the sighting dominant eye (mean spatial frequency shift over all subjects is 21%) compared to that on the non-sighting dominant eye (mean spatial frequency shift over all subjects is 25%). This difference was significant at the 1% level (t=6.4, df 7, p<0.01).

12.7.3. The Direction of Maximum Transfer of the Spatial Frequency Shift and Ocular Asymmetry Measures.

All subjects show a greater asymmetry in the transfer of the spatial frequency shift in one direction compared to that in the opposite direction (see Table 12.2). This direction of maximum transfer was compared to the measures of ocular asymmetry (see Table 12.1). The magnitude of the transferred aftereffect is expressed as a percentage of the magnitude of the aftereffect measured monocularly (ie. the eye that was tested was adapted). The amount of spatial frequency shift added to the test grating in the right eye (left eye) in order to null the spatial frequency shift aftereffect resulting from adaptation of the left eye (right eye) is compared to the amount of shift that had to be added to the right eye to null the aftereffect resulting from adaptation of the right eye. The percentage transferred spatial frequency shifts are shown in Table 12.3 for each subject.

Table 12.3 Transferred Spatial Frequency Shift as a percentage of the Monocular Condition (eye tested is also adapted).

Transfer condition		LE -> RE	RE -> LE
Monocular condition		RE -> RE	LE -> LE
Subjects:	SM	66.5	83.8
	DM	47.6	60.9
	PR	56.1	96.8
	PC	57.3	64.0
	EM	58.8	81.1
	EB	88.1	98.6
	SW	97.1	53.4
	SK	43.8	32.4

Using the ocular asymmetry measures outlined in Table 12.1, maximum transfer was found to be greater from the dominant to the non-dominant eye than in the reverse direction for:

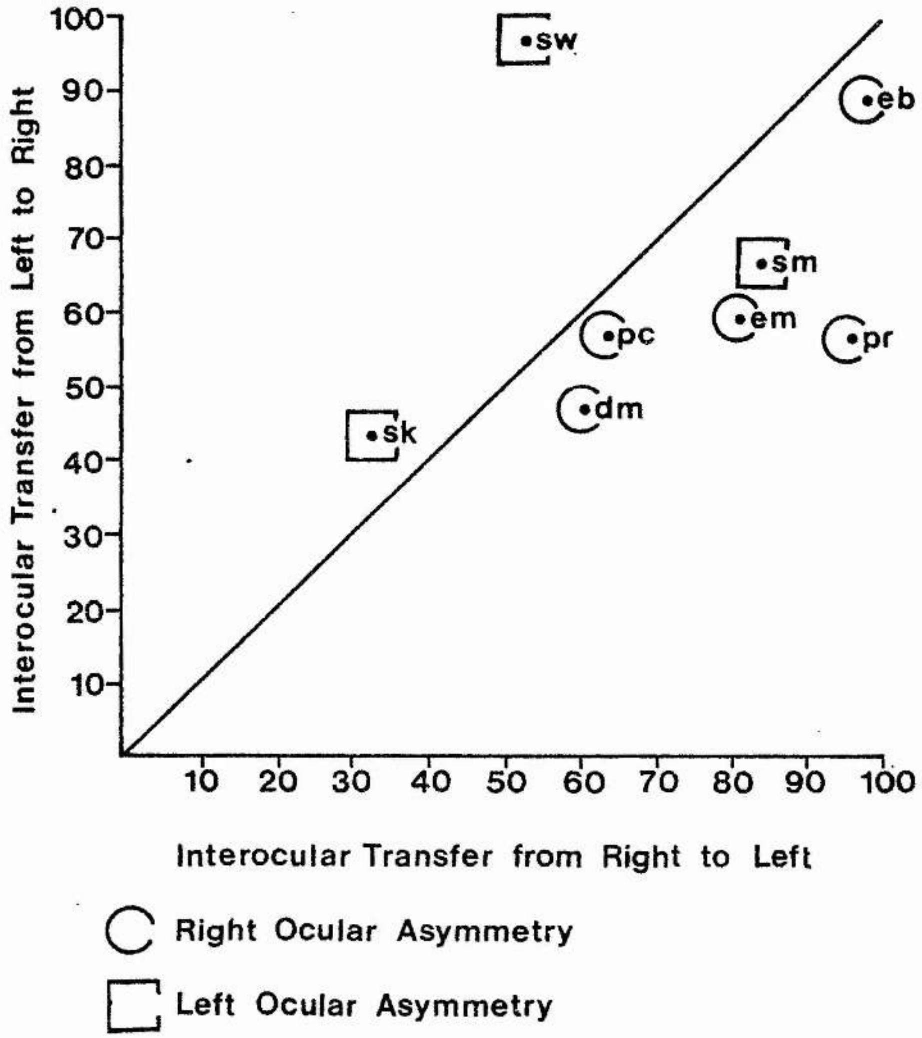
i) Seven out of the 8 subjects using the large disparity asymmetry (dominance) scores (2). The overall mean percentage of transferred aftereffect is 76.1% from the dominant to the non-dominant eye compared to 59.69% from the non-dominant to the dominant ($t=2.38$, df 7, $p<0.05$, 1-tailed test). See Fig. 12.2.

ii) Six out of the 8 subjects using the rivalry dominance scores. The overall mean percentage transferred spatial frequency shift from the dominant eye to the non-dominant eye is 74.7% compared to 61.1% for the opposite direction. There is no significant difference in the magnitudes of transferred aftereffect in the two directions ($t=1.75$, df 7, not significant).

iii) One out of the 8 subjects for the sighting dominance results. 53.4% from the sighting to the non-sighting eye and 77.4% in the reverse direction.

(2) If the small disparity discrimination measures are used 5 out of the 8 subjects show greater transfer from the dominant to the non-dominant eye than in the reverse direction.

Fig 12.2 Percentage Transfer of the Spatial Frequency Shift from the Right to Left Eye Plotted against the Percentage Transfer from the Left to Right Eye.



The agreement reported between the direction of the large disparity discrimination asymmetry measures and the direction of maximum transfer, suggests that the interocular transfer paradigm can also be used as a measure of ocular asymmetry. In the transfer condition of maximum shift it is arbitrary which is the dominant eye ie. the adapted or the tested eye. Some studies (Movshon et al, 1972; Mitchell and Ware, 1974; Mitchell, Reardon and Muir, 1975; Wade, 1976) have found maximum transfer from the sighting dominant eye to the non-dominant eye and the adapted eye is therefore designated the dominant eye. If only transfer information is available the adapted eye in the transfer condition would be designated the dominant eye. This procedure is adopted here in this study.

12.7.4. Interocular Transfer Measures of Ocular Asymmetry

Measures of ocular asymmetry were derived from the two transfer conditions using the mean magnitudes of the spatial frequency shifts in the following formula:

$$\text{Ocular Asymmetry Score} = \frac{(LE \rightarrow RE)-(RE \rightarrow LE)}{(LE \rightarrow RE)+(RE \rightarrow LE)} \quad (3)$$

(LE→RE) = the magnitude of the spatial frequency shift tested on the right eye after adaptation of the left eye (See Table 12.2)

(RE→LE) = the magnitude of the spatial frequency shift tested on the left eye after adaptation of the right eye (see Table 12.2)

(3)Asymmetry measures can also be derived from the transferred aftereffects expressed as a percentage of the monocular test condition as shown in Table 12.3. The asymmetry measures using this data are shown in Table 12.5H in the Appendix H. These transfer measures are referred to as normalised transfer measures. However, the magnitudes of the spatial frequency shifts were different for the two monocular viewing conditions (significant if sighting dominance is used) and may affect the asymmetry scores. The correlation coefficient for the measures derived from the two methods is r=0.48 which is not significant.

The measures of ocular asymmetry for each subject are shown in Table 12.4. A positive value indicates a left ocular asymmetry and a negative value indicates a right ocular asymmetry.

Table 12.4 Measures of Ocular Asymmetry

Subjects:		
	SM	+0.23
	DM	+0.05
	PR	-0.16
	PC	-0.134
	EM	-0.034
	EB	-0.04
	SW	+0.168
	SK	+0.053

The mean degree of asymmetry is 0.11 (direction of dominance is ignored).

12.7.5. Interocular Transfer Measures of Ocular Asymmetry and Ocular Asymmetry Measures from Previous Experimental Procedures

The correlation coefficients for the above asymmetry scores (4) with measures derived from previous experimental procedures are as follows:

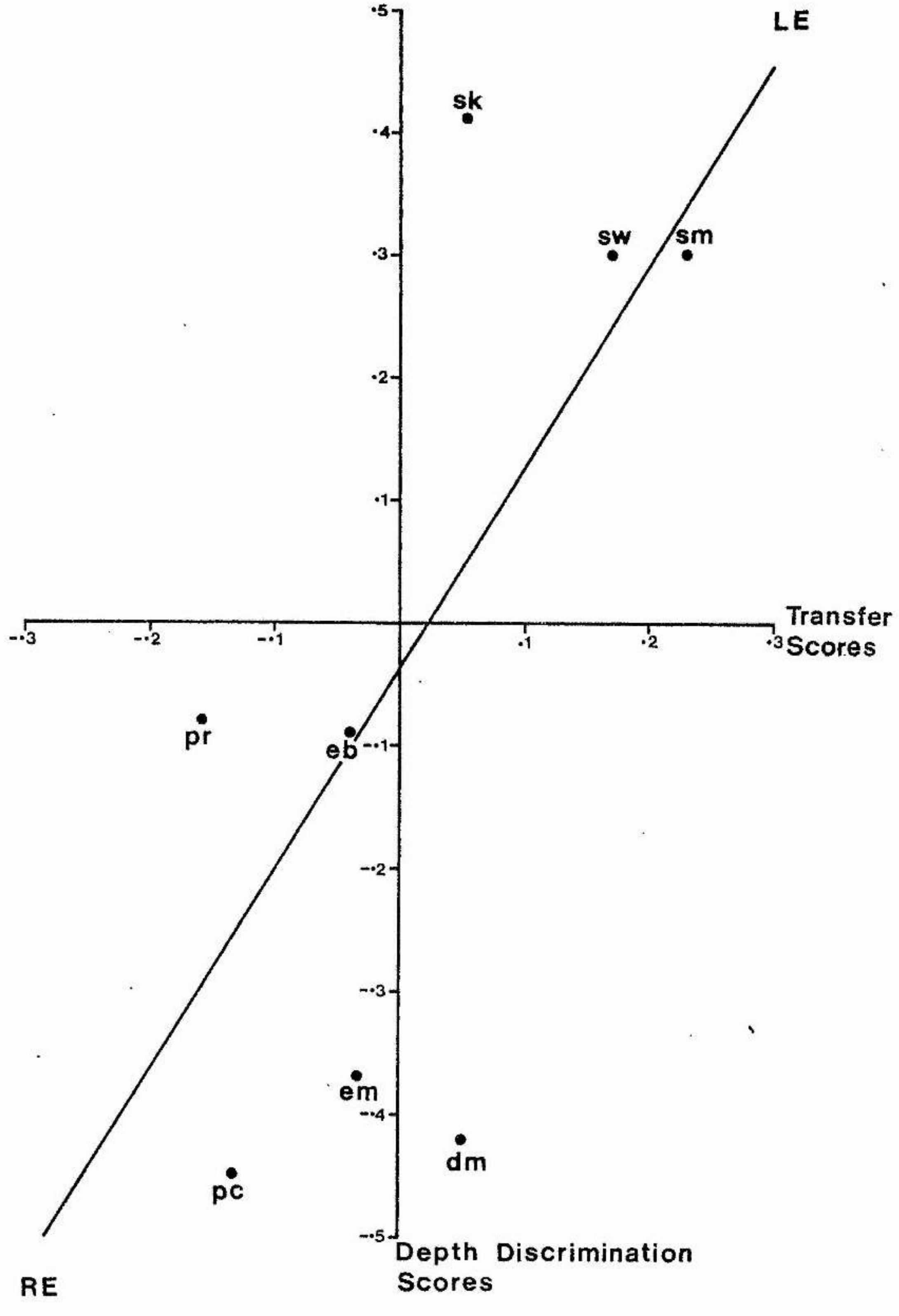
1) with the large disparity discrimination measures, r=0.73 which is significant at the 2% level (1-tailed test) (5). A scatterplot of these scores is shown in Fig 12.3 (6) with the linear regression line equation $Y = -0.0373 + 1.673X$.

(4)The measures of ocular asymmetry using the normalised transfer data were compared with the other measures of ocular asymmetry and the correlation coefficients are shown in the Appendix H.

(5)The small disparity depth discrimination measures correlated with the interocular transfer measures (Table 12.1) with a coefficent of r=0.63, which is significant at the 5% level (1-tailed test).

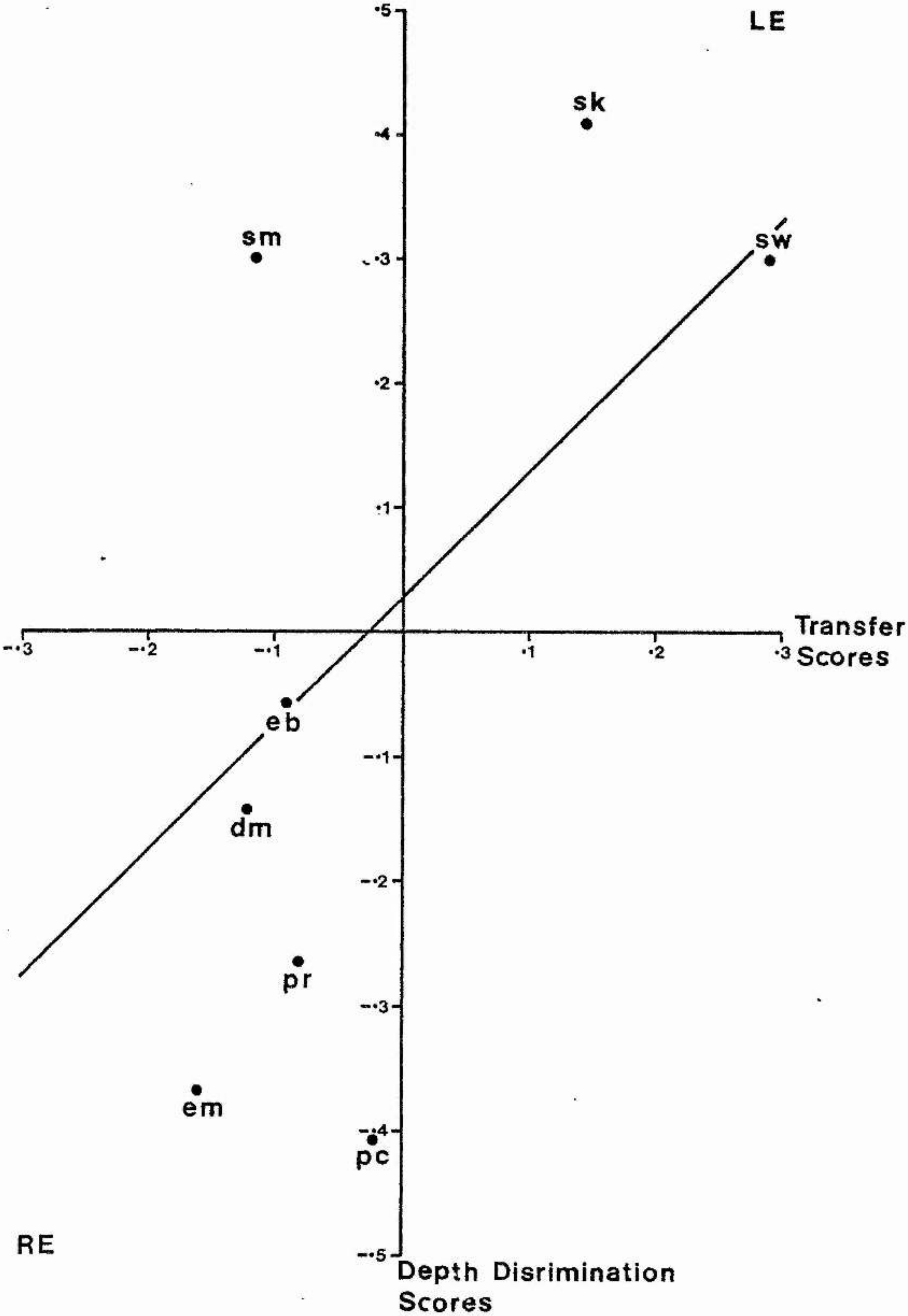
(6)Fig 12.4 shows the scatterplot of the large disparity discrimination measures with the normalised transfer measures of ocular asymmetry. The equation for the linear regression line is $Y = 0.0278 + 0.987X$.

Fig 12.3 Ocular Asymmetry Scores from the Interocular Transfer Experiment and the Depth Discrimination Experiment with Large Disparities (24'/28' of arc).



r= 0.73, $p < 0.02$.

Fig 12.4 Ocular Asymmetry Scores from the Interocular Transfer Experiment using the Normalised Data (see Table 12.5H, Appendix H) and the Depth Discrimination Experiment with Large Disparities (24'/28' of arc).



r = 0.56, not significant.

2) with the binocular rivalry measures of ocular asymmetry, r=0.40 which is not significant.

12.8. Discussion

The interocular transfer of the spatial frequency shift (overall mean of two conditions) is 67% of the spatial frequency magnitude in the monocular viewing condition (overall mean of two monocular viewing conditions). This value compares favourably with the transfer magnitudes reported for other visual aftereffects (Moulden, 1980) and supports the second hypothesis. Blakemore et al (1970) reported a 50% transfer of the spatial frequency shift of the magnitude in the monocular viewing condition.

There was no difference between the magnitudes reported for binocular viewing and monocular viewing of the adapt and test frequencies confirming the first hypothesis. It is possible that binocular rivalry may occur with the binocular viewing condition especially if there was a slight misalignment of the oscilloscopes or displays. However, it has been reported that the magnitude of an aftereffect is not affected by superimposed phenomenal rivalry relative to the condition where no rivalry is experienced (Blake and Fox, 1974; Lehmkuhle and Fox, 1975a; Wade and Wenderoth, 1978; O'Shea and Crassini, 1981b). No subject reported experiencing rivalry and the alignment of the displays was checked after each experimental session. The results reported here support the predictions from one model on interocular transfer (Moulden, 1974, 1980) and will be discussed in chapter 14.

12.8.1. Monocular Viewing and the Magnitude of Spatial Frequency Shift

The third hypothesis was not supported by any of the ocular asymmetry measures or dominance results. There was no difference in the magnitudes of the spatial frequency shift reported for the monocular adapt and test conditions between the dominant and non-dominant eyes when dominance is defined by the large disparity depth discrimination procedure and also by binocular rivalry procedure. This is perhaps not surprising as the two latter procedures are binocular measures of ocular asymmetry which may not necessarily be reflected in differential performance levels when testing is monocular.

Sighting dominance tests can be considered to be monocular testing procedures despite binocular viewing (Barbeito, 1981). All eight subjects had a smaller spatial frequency shift on the sighting eye relative to the non-sighting eye. This difference in magnitude was significant. Similar results, although non-significant, have been reported in other studies using the tilt-aftereffect (Movshon, Chambers and Blakemore, 1972; Mitchell and Ware, 1974).

A difference in the two monocular conditions corresponding to the non-sighting and sighting eyes may reflect possible acuity differences. Acuity was not measured in this study. However, it has been reported to be unrelated to sighting behaviour (Gahagan, 1933). Also visual aftereffects have been reported in amblyopic eyes that differ markedly in acuity (Anderson, Mitchell and Timney, 1980; Keck and Price, 1982) and acuity differences have also been reported to make no difference to the aftereffect magnitudes with binocularly normal subjects (Wade, personal communication, 1976).

Asymmetrical interocular suppression is unlikely to explain the difference between the sighting and non-sighting eyes. Rivalry dominance measures are more likely to reflect this process of asymmetry, yet in this study these results are unrelated to the subjects sighting dominance results. Also, it was reported above that phenomenal rivalry does not influence the growth and magnitude of visual aftereffects.

It is possible that a difference in scanning or saccadic eye-movements may be responsible for the results. If the adapting stimulus is fixated, afterimages may develop and reduce the threshold sensitivity of the display and possible reduce the adaptation effects (Smith, 1977). If the eyes scan the display less frequently when the adapting stimulus is displayed to the sighting eye the magnitude of the aftereffect may be reduced relative to that of the non-sighting eye adapting condition. However, both eyes viewed displays during adaptation and test although only one eye was presented with a stimulus pattern. Binocular eye movements ie. saccadic eye movements have been reported to be more stable than movements made with only one eye open (Rose, 1978). Therefore, as both eyes are open in both monocular adapt/test conditions the saccadic movements would not be expected to differ between the two conditions of monocular presentation of the stimulus to one eye relative to presentation to the other.

No satisfactory explanation can be given to account for the relationship between the spatial frequency shift magnitude and sighting dominance. The failure to find a relationship between ocular asymmetry measures and monocular spatial frequency shift magnitudes suggest that monocular testing (adapt and test same eye) may not be a good indicator of ocular asymmetry in binocular vision. Subjects were unaware of which eye was being adapted and tested.

12.8.2. Direction of Maximum Transfer and Ocular Asymmetry

The fourth hypothesis is partially supported by the asymmetry measures from the depth discrimination and binocular rivalry procedures but not for the sighting dominance results. Greater transfer of the spatial frequency shift is reported from the dominant to the non-dominant eye for seven of the eight subjects defining dominance by the large disparity depth discrimination measure. The difference was also significant. If interocular transfer is indicative of binocular processing as has been suggested then these results suggest that there is an asymmetry in binocular processing towards one eye that is similar to the asymmetry reported in the depth discrimination experiment with large disparity displays using selective attenuation. Binocular rivalry is also a dichoptic or binocular viewing paradigm, and greater transfer is recorded for six of the subjects from the rivalrous dominant to non-dominant eye. These results suggest that interocular transfer of visual aftereffects can be used as a measure of binocular ocular asymmetries. The adapted eye is designated the dominant eye which is supported by previous studies (Movshon, Chambers and Blakemore, 1972; Mitchell and Ware, 1974; Ware and Mitchell, 1974) and also by the close relationship between the measures of ocular asymmetry reported above and the direction of maximum transfer.

The results in this study fail to support previous findings of a significant relationship between the direction of maximum transfer and the sighting dominant eye. Only one subject showed greater transfer from the sighting dominant eye to the non-dominant eye relative to the reverse direction. However, if interocular transfer measures reflect binocular processing it would not necessarily be expected to relate to performance measures where the nature of the testing has been monocular. Sighting dominance using a dichotomous classification is not a useful test of asymmetries in binocular processing.

Why have several studies found greater transfer from the sighting to non-sighting eye than vice versa? (Movshon et al, 1972; Mitchell and Ware, 1974; Mitchell, Reardon and Muir, 1975; Bjorklund and Magnussen, 1981). All these studies used opaque occlusion in their transfer conditions. It is possible that an opaque occluder may have resulted in masking effects or suppressive influences that interacted with the factors determining eye dominance (in this case, sighting dominance), although it is not certain how this may have occurred. (Also it has been argued that sighting dominance is related to the position of the egocentre, Barbeito, 1981). Wade (1976a) reported greater transfer from the sighting dominant to non-sighting eye for the movement aftereffect relative to the opposite direction but this difference was not significant. He used an occluder. Wade and Wenderoth (1978) and Heeley (1979) both used equivalent occlusion and reported transfer to be greater from the non-sighting to sighting eye relative to the opposite direction. It is possible that equivalent occlusion does reduce the difference in magnitude between the directions when they are defined in terms of sighting dominance.

12.8.3. Interocular Transfer Measures of Ocular Asymmetry

Measures of ocular asymmetry were derived from the two transfer conditions specifies both the direction and degree of asymmetry. The direction of maximum transfer is related to the large disparity depth discrimination measures and also the binocular rivalry measures. The amount of transfer of the spatial frequency shift is also related to the degree of this asymmetry as measured by the large disparity depth discrimination procedure only (Fig 12.3).

Transferred visual aftereffects are assumed to depend on binocular processing as is stereoscopic stimulation. The close agreement between these measures may suggest a common basis to the asymmetry measures despite different experimental paradigms. The process responsible for asymmetrical transfer must according to this arguement be differentially responsive to selective attenuation of the two eyes (in the same direction and by the same amount) to result in similar asymmetries of the stereoscopic latencies with the large disparate displays. The ocular asymmetry measures derived from the large disparity discrimination procedures are believed to involve the vergence system. Assuming both measures have a common base the binocular centre that subserves the vergence system may well be the binocular centre mediating the transfer effects.

Alternatively, the binocular centre mediating transfer and the centre subserving vergence movements and responsive to large disparate displays may be independent but be equally asymmetrically responsive to the two eyes.

Two models of interocular transfer are discussed in chapter 14 that are concerned with the magnitude of visual aftereffects under different viewing conditions. The models will be examined in relation to the different magnitudes of the spatial frequency shift for the two directions of transfer reported in this study which may provide some insight into the basis to the ocular asymmetry measures derived from the depth discrimination procedure with large disparities. It is also assumed that the asymmetries in transfer are not restricted to spatial frequency processing but reflect asymmetries in the binocular system that processes other visual stimuli. Several visual aftereffects such as tilt (Movshon, Chambers and Blakemore, 1972; Mitchell and Ware, 1974), the motion aftereffect (Mitchell, Reardon and Muir, 1975; Wade, 1976) and contrast threshold elevation (Ware and Mitchell, 1974) show transfer of 50 and 70% of the monocular condition suggesting other aftereffects could have been used instead of the spatial frequency shift to derive this measure of ocular asymmetry.

The results from this experiment suggest that the ocular asymmetry measure derived from the large disparity depth discrimination experiment is a valid indicator of asymmetry in binocular processing as supported by the relationship with measures of binocular asymmetries using the interocular transfer paradigm.

12.8.4. Mean % Spatial Frequency Shift in the Transfer Conditions

The mean amount of transferred spatial frequency shift was roughly constant between subjects. However, subjects DM and SK show low levels of transfer, 54% and 38% respectively (see the right hand column in Table 12.2). The latter subject may be classed as possibly abnormal if criteria used in other studies is applied (Maraini and Porta, 1978; Keck and Price, 1982). These low levels of transfer do not appear to be related to any other factors such as extreme dominance or extreme asymmetry in transfer (Keck and Price, 1982, reported a relationship between the degree of transfer and the asymmetry in direction of transfer for a group of subjects with varying levels of binocular vision). These mean values of transfer are compared to stereo-acuity measures for each subject and are reported in chapter 14.

12.9. Summary of Chapter 12

The spatial freqency shift was measured in five viewing conditions using a nulling technique. Adapting to two gratings with a ratio of approximately 2:1 resulted in an overall spatial frequency shift of the test grating (1:1) of 23%. The magnitudes of the aftereffects in the two monocular viewing conditions were not significantly different from the magnitude reported in the binocular viewing condition. However, the transfer conditions generated the smallest aftereffect magnitudes, the mean transfer magnitude being 67% of the mean monocular magnitude. This compares favourably with the percentage transfer reported for other visual aftereffects in the literature.

The spatial frequency shifts generated for the two monocular conditions for the dominant and non-dominant eyes were not significantly different when dominance was defined by the large disparity depth discrimination and binocular rivalry procedures. However, the spatial frequency shift was significantly smaller on the sighting eye relative to the non-sighting eye. No satisfactory explanation was offered for this latter finding.

Transfer was greater in one direction relative to the other and was not related to sighting dominance. The direction and amount of transfer of the spatial frequency shift was significantly related to the direction and degree of asymmetry derived from the large disparity depth discrimination measures. The adapted eye in the transfer condition was designated the dominant eye. It was suggested that the ocular asymmetry results from both procedures may share a common binocular basis but that the asymmetry was not restricted to the processing of spatial frequencies.

The mean transferred spatial frequency shift for each subject is discussed in the following chapter.

CHAPTER 13

Measurement of Stereothresholds and Transfer of the Spatial Frequency Shift

13.1. Introduction

The percentage of interocular transfer of visual aftereffects between the two eyes has been used by other authors as an index of the level of binocular functioning of the visual system. Transfer of a visual aftereffect (testing on the eye that has been adapted) has been reported to be between 50 and 60% of the magnitude of the aftereffect measured in the monocular viewing condition. Stereo-blind individuals with a history of childhood strabismus have frequently been reported to have reduced transfer of visual aftereffects (Movshon, Chambers and Blakemore, 1972; Mitchell and Ware, 1974; Lema and Blake, 1977). These individuals have been assumed to have a reduced complement of binocular neurones relative to subjects who possess good stereopsis.

Support for this view comes from neurophysiological work carried out on animals. The majority of cells in the visual cortex of the cat and monkey are binocularly driven by one or other eye (Hubel and Wiesel, 1962, 1968). Abnormal visual experience during the sensitive period of development of the visual system is known to disrupt these binocular connections: misalignment of the visual axes of the two eyes or discordant input of visual stimuli produced by prismatic deviation reduces the proportion of the binocular neurones (Hubel and Wiesel, 1965; Blakemore, 1976; Maffei and Bisti, 1976). Animals that have been subjected to such rearing practices show a behavioural deficit in their ability to use disparity information as a cue to depth and distance (Blake and Hirsch, 1975; Packwood and Gordon, 1975). These animals are termed stereoblind.

Stereoblind individuals with a history of strabismus are assumed to have a reduced proportion of functionally normal binocular neurones (Bank, Aslin and Letson, 1975; Hohmann and Creutzfeldt, 1975). Typically, they fail to show normal transfer of visual aftereffects: the tilt aftereffect (Movshon, Chambers and Blakemore, 1972; Mitchell and Ware, 1974), the motion aftereffect (Mitchell, Reardon and Muir, 1975; Wade, 1976a), and contrast threshold elevation (Ware and Mitchell 1974; Lema and Blake, 1977; Blake and Cormack, 1979a). These subjects have also been reported to show no binocular summation of contrast (Lema and Blake, 1977; Westendorf, Langston, Chambers and Allegretti, 1978).

The neurophysiological work on animals and the psychophysical evidence described above suggest that transfer of visual aftereffects and stereopsis are mediated by the same binocular processes. The transfer paradigm has thus been used as an "index of binocularity" and the level of stereoscopic acuity. Positive correlations have been reported between the level of stereoacuity and the extent of transfer of a visual aftereffect ie. high transfer relates to good stereoacuity. Mitchell and Ware (1974) measured transfer using the tilt aftereffect and reported a positive correlation coefficient of 0.86 between the extent of transfer and stereoacuity for 15 subjects, four of whom had no stereopsis. High levels of transfer were typically associated with good stereoacuity. Mitchell, Reardon and Muir (1975) measured transfer using the movement aftereffect paradigm and reported a similar relationship as above with a correlation coefficent of 0.75 between transfer levels and stereoacuity for 23 subjects, 14 of whom had no history of strabismus. The experiment in this chapter was designed to investigate the relationship between the levels of transfer of the spatial frequency shift reported in chapter 12 and stereothreshold measures for the same subjects.

13.2. Stereoacuity

Objects that lie nearer and further from the fixation point fall on non-corresponding regions of the two retina and are termed disparate. The ability to distinguish between two objects with the smallest possible disparity difference is called stereoacuity. Disparities as small as 2-3 seconds of arc can typically be distinguished (corresponding to a 0.5 mm difference of two needles held 2 metres away) (Cowey and Porter, 1979). Ogle (1964) quotes a level of 10" of arc as the normal level of stereoacuity.

13.2.1. Tests of Stereoacuity

Many studies that have reported depth threshold measurements have used classical stimuli such as the two-rod and three-rod test where it is not always clear which cues to the depth differences are being used.

Stereothresholds can be measured by several different methods although the correlation of these tests have often been reported as poor (Hall, 1982). Hall (1982) investigated the performance of 678 binocularly normal subjects and two groups of subjects with abnormal binocular vision, on four tests of stereoacuity, the Titmus fly test, the Frisby test, the TNO test and a two-needle test. Low but significant correlations between 0.25 and 0.41 were reported between the stereotests for the group of normal subjects. The author suggested that other factors influence performance on the tests for example, some tests were based on non-cyclopean techniques others used random-dot stereograms. With the normal group of subjects using the two-needle procedure, ninety-nine percent had stereoacuities of 37" of arc or better and 5% of these had stereoacuities of 2" of arc. The TNO test consists of a series of random-dot stereograms with varying values of disparity. Subjects were required to make a depth and form discrimination. The mean stereothreshold of the group of binocularly normal subjects on this test was 60" of arc. No monocular form information is available with this test and depth discrimination is dependent on cyclopean stimulation.

The Mitchell et al studies (1974, 1975) used a mirror stereoscope arrangement portraying a monocular visible reference line and a test line to measure the stereothresholds (Mitchell and Hagan, 1972). The subjects task was to set a reference line in the same depth plane as the test target by varying the disparity. This procedure distinguished individuals with good stereoacuity from individuals with poor stereoacuity. Both studies (Mitchell and Ware, 1974; Mitchell et al, 1975) included stereoblind and/or stereo-anomalous observers as well as normals.

13.3. Methodology Adopted in this Study

In the present study all subjects had good stereopsis as established by their performance in their depth discrimination experiments using random-dot stereograms. A cyclopean technique was used to measure stereothresholds rather than using classical stimuli or methods as used in the Mitchell et al studies (1974, 1975). This would ensure that only binocular cues to depth ie. disparity are used and cyclopean stimulation would be compatible with the other stereoscopic displays used in this thesis.

Stereothresholds were measured using a random-dot display that was sinusoidally modulated in depth. The display appeared as a horizontal corrugated iron surface. The depth of surface, ie. the depth from the peak to the trough was dependent on the level of the disparity modulation. Tyler (1974) used a similar type of display to determine threshold sensitivities to depth modulations for different spatial frequencies. The highest spatial frequency that observers could perceive with depth was 4 c/o. Rogers, Graham and Anstis (1980) reported that the maximum sensitivity for sinusoidally modulated depth gratings was between 20 and 30" of arc at corresponding frequencies of 0.3 to 0.5 c/ .

13.4. The Aims of the Experiment

The aim of the experiment reported in this chapter was to investigate levels of transfer in relation to stereoacuities. The spatial frequency shift transfer measures are reported in chapter 12. Stereothresholds were measured in this experiment for the same group of subjects to investigate the following hypothesis:

1) That there would be a positive relationship between the mean percentage transfer of the spatial frequency shift and the level of stereoacuity ie. good stereoacuity would be related to high levels of transfer. The mean percentage transfer has been used by some authors as a gauge of stereoacuity (Mitchell and Ware, 1974; Mitchell et al, 1975).

And in addition,

2) To investigate the relationship between the stereoacuity measures and the measures of ocular asymmetry using the large disparity depth discrimination procedure and the interocular transfer procedure. In a study by Keck and Price (1981), subjects who showed a greater asymmetry in the direction of transfer had low mean values of transfer of the visual aftereffect. In the previous study described

in chapter 12, a relationship was found between the direction and degree of asymmetry in transfer and the direction and degree of ocular asymmetry measured by the large disparity depth discrimination experiment.

13.5. Method

13.5.1. Subjects

Eight subjects from the previous experiment participated in this experiment.

13.5.2. Apparatus

Subjects viewed displays 57 cms away in the same modified stereoscopic arrangement as used in the previous study. Identical random-dot patterns were generated on each scope by the Nova 1220. Each display was composed of 64 x 64 dots.

A sinusoidal voltage was derived from a Farnell digital synthesised generator (DSG1). The amplitude was controlled by a resistor ladder, with 15 steps or voltage increments. The output from the generator was fed to the X-input of the right scope only to introduce binocular disparities between the two eyes. The frequency of the display was set at 0.5 cycles per degree.

When fused the display appeared as a series of horizontal waves in depth. The central black fixation point was present all the time positioned midway between a trough and a peak. A change in the amplitude of the right display changed the disparity modulation such that a single step on the ladder produced an equivalent disparity change of 4.2 seconds of arc.

The displays subtended a visual angle of $4^{\circ} \times 4^{\circ}$ but were masked down to square apertures $3.7^{\circ} \times 3.7^{\circ}$ in order to obscure the distorted vertical edges of the right display which could have provided extraneous cues to depth. The space-average luminance of the displays was 11 cdm-2. Two switch keys were provided to record the responses.

13.5.3. Procedure

The experiment was controlled on-line by the computer which also recorded the responses to the presence or absence of depth.

Each subject participated in a preliminary session to establish the approximate level or range for the stereothreshold measurements. The experimenter decreased the disparity signal until the modulated surface in depth appeared as a flat textured display. Subjects were required to state when they saw no depth in the display. This procedure was repeated but the disparity signal was introduced and increased until subjects reported seeing depth again. This gave an approximate indication of the initial starting values for the two staircases. The random-dot configuration of the display remained unchanged throughout the experiment.

A two interleaved random staircase procedure was used. The descending staircase began with a large disparity signal, the modulation in depth being easily recognisable. The ascending staircase began with no disparity signal or a small depth modulation. Considering one staircase, subjects on the first trial reported that the display appeared modulated in depth. On the following trial, the display was reduced in depth by the stated step size and this reduction continued for each trial until subjects responded that no depth could be seen. On the following trial the depth was increased by one step and if depth was reported it was decreased on the following trial. These trials continued until an asymptotic level was achieved. The other staircase followed the same procedure but the starting value was well below stereothreshold and the disparity signal was progressively increased on the following trials. The two staircases were randomly interleaved. .Two switch keys were provided, one was to be pressed to register that depth was present in the display and the other to indicate that no depth was seen.

A 0.5 second tone preceded each trial and the modulated display was presented for one second. A five second interval followed during which time the random-dot display had zero-disparity. Subjects were asked to fixate the central fixation dot throughout the experimental session.

There were five experimental runs, each run lasting approximately 5 minutes and the average number of trials was 30. The mean of the last 10 reversals were calculated for each experimental run.

13.6. Results

Table 13.1 shows the mean stereothresholds for each subject over the five sessions and standard deviations of the means over trials. The mean stereothreshold is 25.6 seconds of arc. The column on the far right of Table 13.1 shows the mean % interocular transfer (ie. mean transfer expressed as a percentage of the mean monocular condition from experiment in chapter 12).

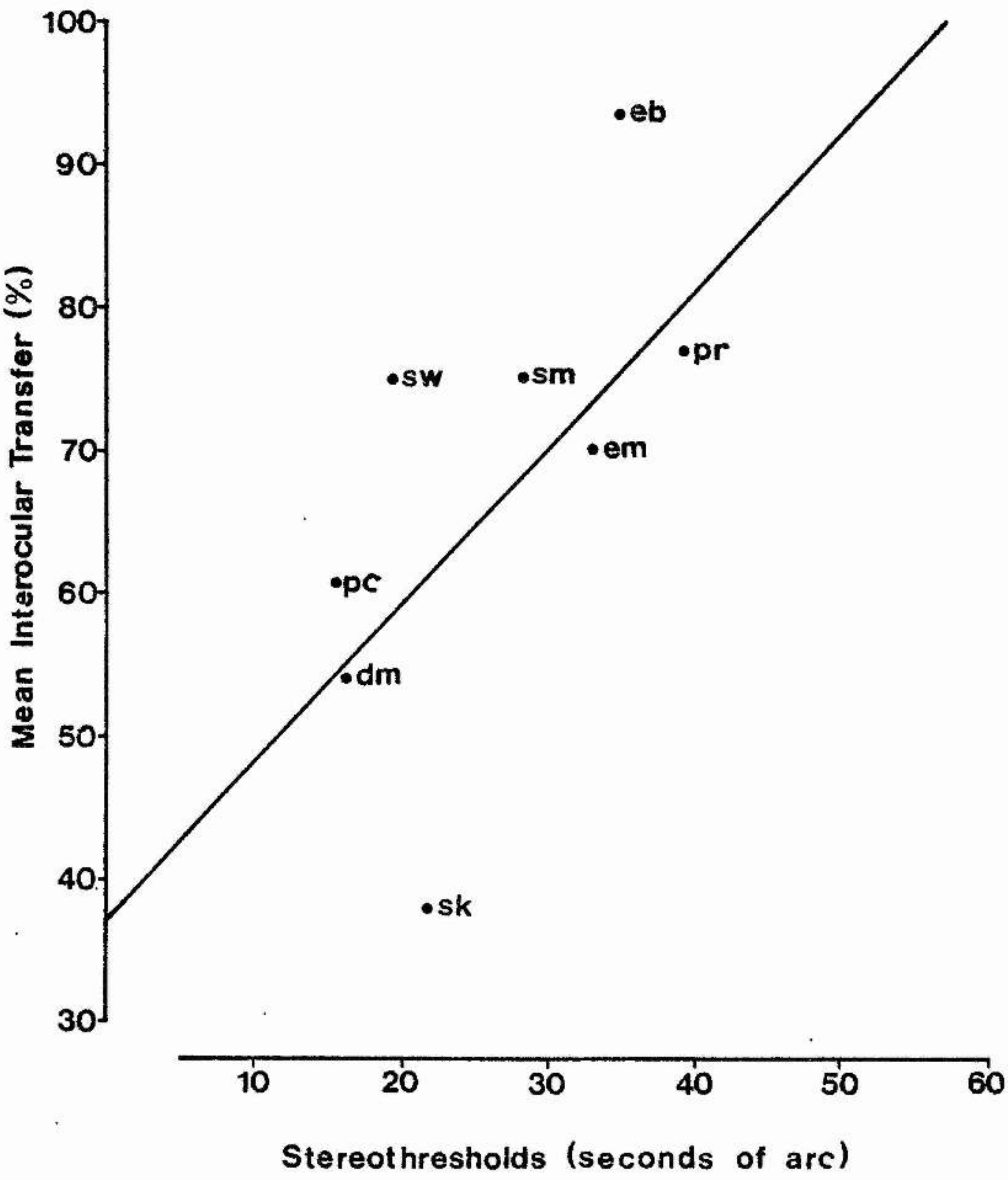
Table 13.1 The Mean Stereothresholds (seconds of arc) and Standard Deviations (SD) and the Mean Percentage (%) Interocular Transfer of the Spatial Frequency Shift

	Stereo-thresholds	+-1SD	% interocular transfer
Subjects:			
SM	28.4	3.57	73.7
DM	16.2	4.00	53.1
PR	39.6	2.77	74.2
PC	16.2	3.19	60.9
EM	33.2	11.39	68.5
EB	35.2	7.22	93.3
SW	19.6	2.75	73.3
SK	22.2	4.65	37.5
Mean	26.33		

13.6.1. Stereothresholds and Mean % Transfer of the Spatial Frequency Shift

The mean percentage transfer is the mean of the two conditions of transfer expressed as a percentage of the mean magnitude of the spatial frequency shift in the two monocular viewing conditions. Fig 13.1 shows the stereothreshold scores plotted against the mean percentage transfer.

Fig 13.1 Stereothresholds plotted against the Mean Percentage Transfer of the Spatial Frequency Shift.



r = 0.62, not significant.

The correlation coefficient of the two measures is r=0.62 which is high but not statistically significant. The equation for the linear regression line is $Y = 38.85 + 1.07X$. However, the trend shows that a high percentage of transferred aftereffect is associated with a high stereothreshold, a result opposite to that expected from previous findings.

13.6.2. Stereothreshold and Ocular Asymmetries

The ocular asymmetry measures for each subject are listed below for the large disparity discrimination procedure described in chapter 9 and the interocular transfer measures reported in chapter 12.

Measures of Ocular Asymmetry:

		1. Large disparity Discrimination	2. Interocular Transfer
Subjects:	SM	0.30	+0.23
	DM	-0.14	+0.05
	PR	-0.08	-0.16
	PC	-0.41	-0.134
	EM	-0.37	-0.034
	EB	-0.09	-0.04
	SW	0.30	+0.168
	SK	0.41	+0.053
	EC	0.18	-----

There is no relationship between the large disparity discrimination measures of asymmetry and the stereothreshold levels, the correlation coefficient is r=-0.10 which is not significant. The correlation coeficient for the interocular transfer measures and the stereothresholds is r = -0.32 which is also not significant.

13.7. Discussion

All subjects had stereothresholds below one minute of arc, the mean stereothreshold being 26" of arc. This figure corresponds favourably with the stereo-sensitivity range of 20-30" of arc for modulated arrays in depth of 0.3 to 0.5 c/o reported by Rogers, Graham and Anstis (1980) and Schumer and Ganz (1979). Lower stereothresholds have been reported using other non-cyclopean techniques and procedures of measurement (Ogle, 1964).

However, despite slightly higher thresholds found with this procedure relative to results reported using other procedures in the literature it would not be expected to affect the relative ordering of subjects on their levels of stereo-acuity.

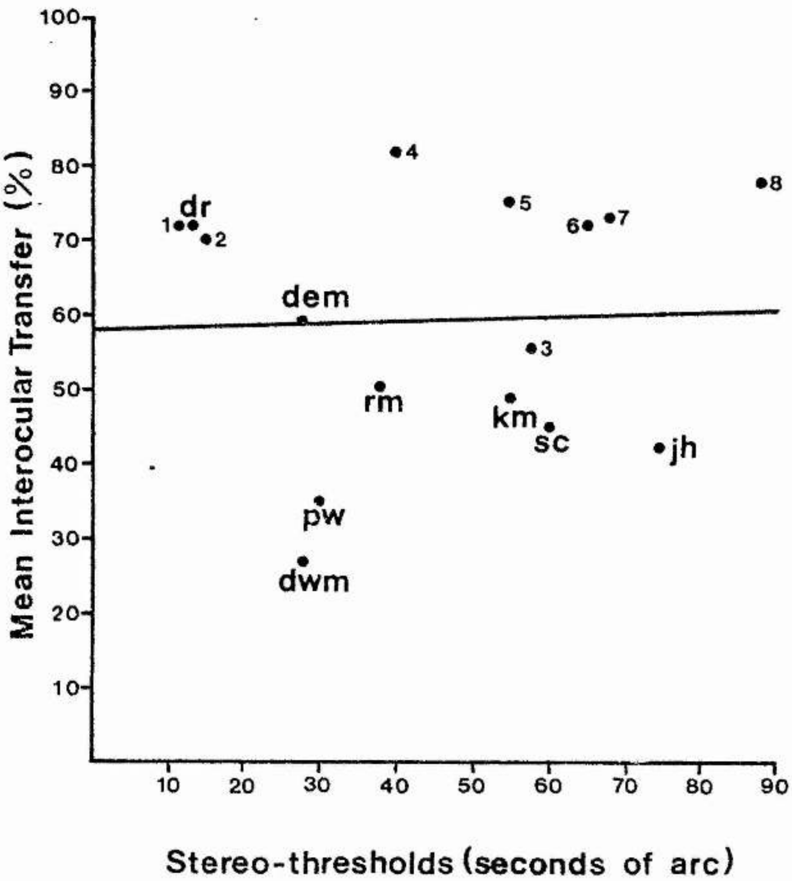
The results of this study fail to support the hypothesis that high levels of transfer are related to low stereothresholds (Mitchell and Ware, 1974; Mitchell, Reardon and Muir, 1975; Mann, 1978). There was a non-significant relationship between the two and the trend is also opposite to that predicted from these studies. Subjects PR and EB have high levels of transfer, 74 and 93% respectively and have two of the highest stereothresholds relative to other subjects. Subject SK, who was reported to have a level of transfer below that expected of normal binocular functioning subjects has a stereothreshold of 22.2 seconds of arc. Mitchell et al (1975) reports that one subject with a mean interocular transfer of 70% has a stereothreshold of 12" of arc.

In this study subjects were required to indicate if depth was present in the display which was presented for one second. The subjects task was not a true two alternative forced-choice procedure. The responses may be contaminated by decision criteria adopted by the subjects ie. some subjects may have responded that depth was not present even when the disparity level was high and above stereothreshold. Subject SW is well practiced in psychophysical procedures and shows a low stereothreshold as well as a high percentage transfer figure. A true forced-choice procedure eg. a two-alternative interval forced-choice technique would have overcome this problem. With this procedure two trials are presented one after the other but only one shows the display modulated in depth. The subjects task is to determine in which of the two intervals or trials the display was modulated in depth. This procedure would be used in conjunction with the modified staircase technique similar to that described by Taylor and Creelman (1967) called PEST. Therefore, given the procedure used here and the above criticisms the relationship shown in Fig 13.1 should be interpreted with caution.

It is interesting to examine the data for subjects with good stereo-acuity reported in the Mitchell et al studies (1974, 1975). For subjects with stereoacuities under 1.5° there is no specific trend or significant relationship between stereothreshold levels and the amount of transfer of a visual aftereffect. The hypothesis in its strong form (Mitchell and Ware, 1974) is not supported by their own results when stereo-anomalous observers are taken out of the sample. Fig 13.2 shows the transfer measures and the stereothreshold measures for the group of subjects in the Mitchell et al studies (1974, 1975) that had depth thresholds below 1.5°. Mean % transfer is not a good predictor of stereo-sensitivity in a group of binocularly normal subjects. However, the results do support the weak form of the hypothesis: transfer is a crude measure of binocular integrity which may or may not be associated with good stereoscopic vision for a group of subject with mixed levels of binocular function. Therefore, there is a qualitative association between transfer and levels of stereoacuity but quantitatively binocular normal subjects do not support the original hypothesis. The results reported here are not inconsistent with those reported in other studies using binocular normal subjects. The hypothesis that transfer of visual aftereffects and stereopsis are mediated by the same binocular channels is under question and will be discussed in the following chapter.

From the results reported in this thesis, there is no relationship between the degree of ocular asymmetry and the level of stereoacuity. This is not surprising given the proposed involvement of eye movement factors as a basis to the ocular asymmetry results. Neither is performance at threshold predictive of performance at suprathreshold. Stereoacuities bore no relation to the stereopsis latencies for depth discriminations with small disparity displays.

Fig 13.2 Stereothresholds Plotted Against the Mean Percentage Transfer of the Tilt and Motion Aftereffects from the Mitchell and Ware (1974) and Mitchell, Reardon and Muir (1975) Studies Respectively.



r = 0.0608, not significant.

13.8. Summary of Chapter 13

Stereothresholds were measured using random-dot displays sinusoidally modulated in depth. The overall mean stereothreshold was 26.3" of arc which compared favourably with other reports using similar displays.

Subjects' stereothresholds fell within the range 16.2 to 39.6" of arc. However, there was no relation between these measures and the amount of transfer of the spatial frequency shift. The trend of the two measures was opposite to that which was expected, in this study high transfer levels were generally associated with relatively poor stereoacuity. Response bias may have been operating to influence stereothreshold settings as the procedure was not a true forced-choice procedure. Some subjects may have been cautious in their settings and not responding to the information available. Therefore, the association between the two measures should be interpreted with caution.

However, previous studies that reported significant correlations between the two measures included stereo-anomalous observers and when excluded from the sample, the binocularly normal subjects showed no such significant correlation (Mitchell et al, 1974, 1975). It was concluded that the results reported in this study and those of Mitchell et al (1974, 1975) support only a weak form of the hypothesis (Movshon et al, 1972; Mitchell and Ware, 1974). The percentage interocular transfer can be used as an index to the level of binocular processing of the visual cortex which may also be associated with stereoscopic ability ie there is a qualitative relationship but not quantitative relationship between the levels of stereoacuity shown in binocularly normal subjects and the amount of transfer of a visual aftereffect.

There was significant no relationship between stereothresholds and the measures of ocular asymmetry.

CHAPTER 14

Models of Interocular Transfer of Visual Aftereffects

14.1. Introduction

The interocular transfer paradigm reported in chapter 12 involved adaptation and testing under different viewing conditions resulting in differential levels of the spatial frequency shift. The assumptions behind selective adaptation is that the activity of certain hypothesised populations of neurones are changed. This is the assumption underlying the channel model (Blakemore and Campbell, 1969). The outcome of this changed level of activity is that subsequently viewed stimuli are changed in appearance if they stimulate the same subset of neurones. Thus the results of selective adaptation are interpreted in relation to neurophysiological findings derived from electrophysiological recordings in animals. Interocular transfer techniques may be considered a psychophysical tool for investigating possible cortical substrates hypothesised to mediate certain visual phenomena.

Several models of interocular transfer have been proposed partially based on the limited knowledge of electrode recordings in animals. Both models to be discussed are partially based on hypothesised monocular and binocular units which are differentially adapted under different viewing conditions. The use of models can aid the understanding of perceptual phenomena and with this type of model can be used to infer the cortical structure underlying perceptual effects.

The spatial frequency shift was measured under five different viewing conditions. The asymmetry in transfer was related to the degree and direction of the ocular asymmetry measures derived from the large disparity discrimination experiment. Measures of ocular asymmetry based on the depth discrimination procedures and the binocular rivalry procedure involve binocular stimulation. Therefore, an investigation of the models of interocular transfer in relation to the results in chapters 12 and 13 may further the understanding of the nature of ocular asymmetries reported in this study. Two models are discussed and reviewed to see if they can accommodate the reported spatial frequency shift results. The implications of the models for the binocular asymmetry measures reported in the previous chapters are discussed in terms of the hypothesised cortical processes ie. the binocular and monocular units. If the models cannot accommodate the results possible reformulations or further assumptions may have to be considered.

14.2. Lehmkuhle and Fox's (1975b) model: A simple linear model

A model of interocular transfer was proposed by Lehmkuhle and Fox (1975b) to explain the magnitudes of the motion aftereffect under various viewing conditions. The assumptions of the model are outlined below:

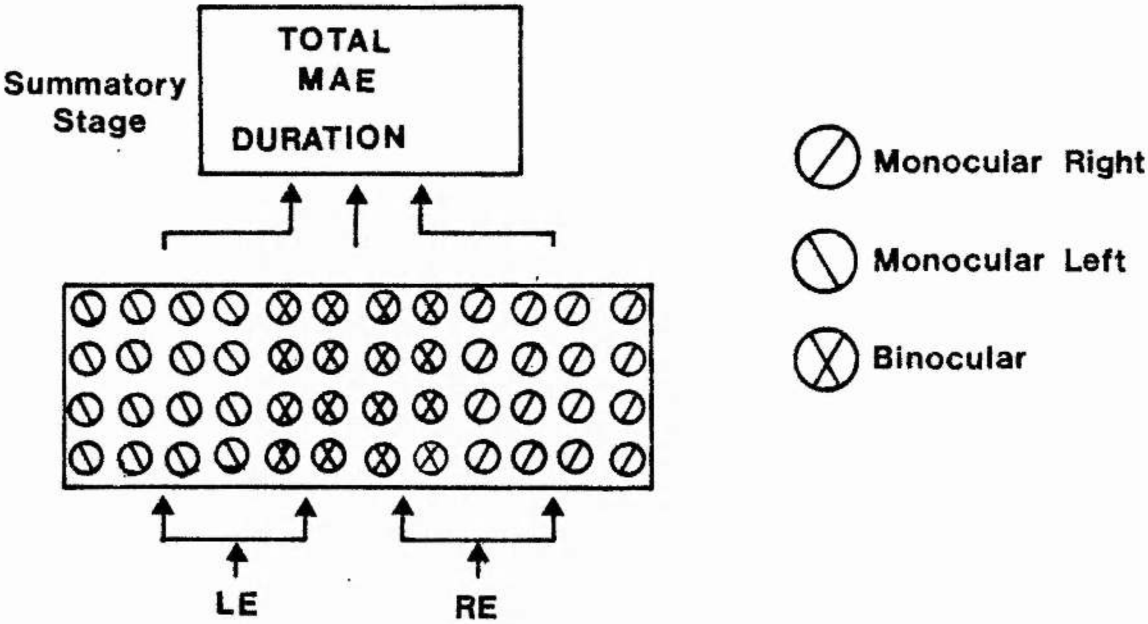
i) There are three independent classes of cells or units; monocular left (ML) driven by the left eye, monocular right (MR) driven by the right eye and binocular (B) driven equally by either eye. These units are independent but converge at a summatory stage (linearly) as shown in Fig 14.1.

ii) The magnitude of an aftereffect is dependent on the number of cells adapted. If more cells are adapted the aftereffect is larger. Binocular viewing stimulates all three sets of units whereas monocular viewing stimulates the binocular set and one monocular set (ie. ML + B or MR + B).

iii) Interocular transfer of an aftereffect is dependent on the binocular units only, the strength or magnitude of the aftereffect is dependent on the number of cells or units adapted and tested. Implicit in the model is the assumption that unadapted monocular units contribute in the test phase of the aftereffect by weakening it (see Blake, Overton and Lema-Stern, 1981). Therefore, in the transfer condition the aftereffect is less than the monocular or binocular aftereffect magnitudes.

iv) Individuals who fail to show transfer of visual aftereffects are assumed not to possess binocular cells and are unlikely to possess stereopsis.

Fig 14.1 The Interocular Model of Lehmkuhle and Fox (1975).



The Different Units Involved in the Four Viewing Conditions.

Viewing Conditions Units Adapted and Tested

1. BINOCULAR AFTEREFFECT = MR + B + ML

2. MONOCULAR AFTEREFFECT = MR + B or ML + B

3. INTEROCULAR TRANSFER = B

4. RIVALROUS AFTEREFFECT = MR or ML (both eyes are adapted to movement in opposite directions and testing one eye engages the monocular set only as the complementary motion in the two eyes does not differentially adapt the binocular set).

(taken from Lehmkuhle and Fox, 1975).

Results of the motion aftereffect (Lehmkuhle and Fox; 1975b) and the tilt aftereffect (Lehmkuhle and Fox, 1976b) measured under the different viewing conditions were in agreement with the predictions of the model. The authors also state that the model provides a rationale for the superiority of binocular performance over monocular performance in binocular summation studies. The model predicts that the magnitude of the aftereffect in the binocular viewing condition will be greater than that generated in the monocular condition. The predictions are derived from the following:

Binocular Aftereffect = B + ML + MR (Adapted and tested) (a)

Monocular Aftereffect = B + ML or B + MR (Adapted and tested)

Therefore, given the assumptionii) above the binocular aftereffect is greater than the monocular aftereffect.

Several of the model assumptions have been tested in a recent study reported by Blake, Overton and Lema-Stern (1981) using the threshold elevation of contrast. The authors, in an attempt to explain incomplete transfer, confirmed the above findings and also reported that i) the binocular cells are responsive to either eye but not to simultaneous stimulation to both eyes, ii) monocular units do contribute to the aftereffect in the monocular viewing condition, iii) monocular and binocular units are equally responsive and iv) incomplete transfer is due to the involvement of unadapted monocular units stimulated in the test phase which weakens the aftereffect. They claimed that ocular dominance, as realised by asymmetrical transfer of a visual aftereffect, could be incorporated into the model by positing a differential in responsiveness of the binocular cells to each eye. However, the authors failed to find evidence of large asymmetries of interocular transfer in their subjects and did not accommodate this feature into the model. All binocular cells were therefore treated as a uniform set.

14.3. Moulden's Model: A three class model (1974,1980) and a five class model (1980)

This model attempts to explain the mechanisms underlying transfer and the partial transfer of visual aftereffects relative to the aftereffect magnitude generated with monocular viewing. The three class model

(Moulden, 1974, 1980) can predict the magnitude of an aftereffect under five conditions of viewing. The assumptions of the model are as follows:

i) There are three classes of neurones or units as above, monocular left, monocular right and binocular. Binocular units are stimulated by either eye or both eyes. All classes are independent and are linearly added to produce an aftereffect under a certain viewing condition.

ii) The magnitude of an aftereffect is dependent on the ratio of the proportion of units both adapted and tested to the proportion of units tested. This differs from the above model that states the aftereffect is dependent on the number of adapted and tested units only.

iii) Interocular transfer involves only binocular neurones but unadapted monocular neurones during testing do contribute to the aftereffect by weakening it.

Moulden measured two aftereffects, the motion aftereffect and tilt aftereffect under five viewing conditions. The obtained results supported the model's predictions. The binocular and monocular aftereffect magnitudes are predicted to be equivalent, as follows:

$$\text{Binocular Aftereffect} = \frac{B + ML + MR \text{ (adapted and tested)}}{B + ML + MR \text{ (tested)}} \qquad \text{(b)}$$

$$= 1$$

$$\text{Monocular Aftereffect} = \frac{B + ML}{B + ML} \text{ or } \frac{B + MR}{B + MR}$$

$$= 1$$

Eye dominance could be incorporated into the model by using a weighting function of the binocular neurones towards one eye (Moulden, 1980, p 46).

The model was extended into a five class model (Moulden, 1980) to accommodate the different levels of response of binocular neurones to each eye or to both eyes that had been arbitrarily designated in the electrophysiological literature into dominance classes (Hubel and Wiesel, 1968). The classes are as follows: class 1 and 5 are driven by one eye only, ie. they are monocular; class 3 are driven by both eyes or either eye; classes 2 and 4 are driven as for class 3 but more strongly by one eye. Three levels of response vigour were incorporated. In the model, the magnitude of the aftereffect is dependent on the vigour of the firing or response rate of that class of units. Differing proportions of units in each class are also incorporated into the model. The reported magnitudes of the aftereffects (motion and tilt) for the transfer and monocular viewing conditions were used to predict the proportion of units in the other dominance classes. The distribution of units in the classes were similar to the observed distribution of classified cells recorded in the monkey visual cortex (Hubel and Wiesel, 1968).

However, the predictions of aftereffect magnitude under the different viewing conditions from the five class model were the same as those predicted by the three class model. It was also assumed that the binocular units fire as strongly to one eye as to both eyes.

Both models assume some level of neural pooling. The size of the aftereffect is the product of the weighted average of the activity of the group of units that are stimulated. The overall level of activity is not dependent on the most sensitive neurone but on the pooled activity of the different neurones (Blake, Overton and Lema-Stern, 1981).

It can be seen that the interocular transfer paradigm is a useful tool for understanding the visual system as it provides the possibility of investigating the different neural channels hypothesised to be responsible for the generation or processing of particular visual stimuli. It provides some understanding of how the hypothesised binocular and monocular channels may mediate visual phenomena. In this not accommodate binocular neurones that are differentially sensitive to each eye. The model cannot explain the results reported in this study.

ii) Moulden's model: Eye dominance is expressed as a simple weighting function of the binocular or monocular class of units towards one eye. Levelt (1965) proposed a model of binocular summation that incorporated weighting functions to explain the eye dominance effects in the equi-brightness curves. The weighting function may take the form of an increase in the firing rate for the class of units driven by one eye relative to the other or a greater proportion of units responsive to one eye relative to the other. However, the magnitude of an aftereffect is dependent on the ratio of the adapted and tested class of units to the proportion of tested units, ie.,

$$\text{Transfer from right to left} = \frac{B}{B + ML}$$

$$\text{Transfer from left to right} = \frac{B}{B + MR}$$

A difference in the magnitudes of these aftereffects can occur only if the proportion of monocular units differ. The pooling of the activity of the unadapted monocular units weaken the transferred aftereffect. To explain the difference in the two transfer magnitudes and the monocular neurones or units carried the weighting function, it would therefore be expected that the magnitude of the aftereffects in the two monocular conditions would differ. Greater monocular aftereffects would be recorded for the eye that was adapted in the transfer condition if this was maximal for this direction of adapt and test. Only three subjects SM, DM and ID show this pattern of results.

The direction of maximum transfer was also related to the binocular measures of ocular asymmetry using the large disparity depth discrimination procedure. The asymmetry therefore is related to binocular processes and not the monocular channels. Assuming that binocular units are differentially sensitive to each eye, it would also study such an approach may further the undertanding of the ocular asymmetry factors and the integration of the signals from the two eyes for the binocular percept.

14.4. The Spatial Frequency Shift Results and Model Predictions

Both Moulden (1980) and Lehmkuhle and Fox (1975b) present data that is confirmatory of their respective models. The models are also assumed to be applicable to other visual aftereffects that also show incomplete transfer. The results from chapters 12 and 13 for the spatial frequency shift will be discussed with reference to these models.

The magnitude of the spatial frequency shift reported in chapter 12 for the monocular viewing conditions was reported to be not significantly different from the spatial frequency shift generated in the binocular viewing condition. The two models predict different results, compare formulae a) and b). The above result is consistent with Moulden's model, that uses the ratio postulate. The results show that binocular and monocular spatial frequency shift magnitudes are equal.

The spatial frequency shift magnitude on the dominant eye for the large disparity measure was no different from the magnitude measured on the non-dominant eye. This was also mirrored for the dominant eye derived from the rivalry procedure.

14.4.1. Transfer of the Spatial Frequency Shift

Asymmetrical transfer of the spatial frequency shift was reported to be significantly related to the large disparity depth discrimination measures of ocular asymmetry (and the rivalry measures for 6/8 subjects).

i) Lehmkuhle and Fox's model: This model postulates that the magnitude of an aftereffect is increased if more cells are adapted and tested. Greater transfer in one direction would suggest a greater proportion of cells or units adapted and tested for adaptation of one eye relative to the other. Transfer is dependent on binocular neurones. An increase in their number to account for greater transfer in one direction would also result in an increase in the magnitude of the aftereffect in the other direction because of the assumed homogeneous level of response to each eye. The model does be expected that the magnitude of the aftereffect in the two monocular conditions would have equivalent differences to the two transfer conditions because adapting and testing the same eye is assumed to stimulate the binocular units. Given that dominance here is defined by the large disparity depth procedures, there was no significant difference in the aftereffects for the monocular dominant eye adapt/test condition and the monocular non-dominant eye adapt/test conditions.

This model is not able to accommodate or explain these findings unless further assumptions are made. It is possible that the monocular and binocular channels have different relative sensitivities. Assuming that binocular units are less sensitive than monocular units when stimulated by one eye; the aftereffect generated in the monocular viewing conditions will depend on the proportion or firing rates of monocular units and any binocular asymmetries (ie. related to the other ocular asymmetry measures) would be masked. Therefore, aftereffect magnitude in the two monocular conditions would be equal. However, in the transfer condition which is dependent on the binocular units, this asymmetry in response level would be realised in differential transfer levels for the two directions. This would assume that the monocular units would contribute less to the pooled activity of units stimulated in the test phase. Therefore, monocular viewing and transfer conditions would not be expected to show equivalent asymmetries that would be related to other ocular asymmetry measures. There is some evidence to support the above hypothesis. Bjorklund and Magnussen (1981) reported that an increase in the adaptation period increased the magnitude of the aftereffect in the transfer condition only. The authors suggested that the monocular channels saturated at a faster rate than the binocular channels and during monocular viewing the binocular channels are less than optimally excited. The binocular channels are believed to become increasingly active with the increase in the adaptation time.

Also it is not known what factors influence the adaptation rates and the levels of adaptation. Spatial aftereffects can be generated to their maximum extent with very brief exposure to the adapting stimulus (Sekuler and Littlejohn, 1974). Given the periods of adaptation used in this study, it would be expected that the channels would be optimally saturated.

However, there is some different evidence to suggest that binocular units may be more sensitive than monocular units. Julesz and Oswald (1978) reported that an increase in dot density of a target that was not discriminable monocularly could be used to facilitate tracking of the target in dynamic random-dot displays when stimulation was binocular. This suggests some binocular units may be more sensitive than monocular units. At low contrasts, testing for example the right eye after adaptation (monocular condition) and the right eye after no adaptation would (transfer) be tapping the binocular units only and the magnitudes of the aftereffects in these two viewing conditions would be equivalent. As contrast increased, the monocular units would become more active and the magnitudes of the transferred effect would decrease as the unadapted monocular units would progressively weaken the binocular aftereffects. A difference in the proportion or response rate between the two classes of monocular units would explain the different transfer magnitudes. The results from the Blake, Overton and Lema-Stern (1981) study failed to support this prediction. However, a difference in contrast sensitivity would not be able to explain the results in this chapter (chapter 12) because suprathreshold stimulation was used in the viewing conditions.

The relation between the interocular transfer measures and large-disparity measures are discussed below.

14.4.2. Appraisal of the Assumptions of the Interocular Transfer Models in the Light of Recent Psychophysical and Neurophysiological Findings

Moulden's model predicts that adapting one eye and testing on both eyes results in a greater aftereffect than the transferred aftereffect. He presented evidence to support this. However, Wolfe and Held (1981) reported the opposite finding. These authors suggested that methodological differences may have contributed to this discrepancy. Moulden's results were claimed to be confounded with the normalization process of perceived vertical. Wolfe and Held (1981) interpreted their own data as evidence for a binocular process that is activated by binocular stimulation only (ie. the right and left eye simultaneously). Given the condition of adapt one eye and test both eyes this process would not have been adapted but would be stimulated during the test phase. These unadapted binocular units would reduce the aftereffect in this condition to a greater extent than the unadapted monocular units in the test phase of the transfer condition. This suggests that binocular units responsive only to both eyes may have to be added to the model. Blake, Overton and Lema-Stern (1981) failed to find evidence of a purely binocular process using the contrast threshold elevation procedure. It is possible that the binocular channel is less sensitive than the other channels and is activated only with suprathreshold stimulation as used in the Wolfe and Held (1981) study.

Wade and Wenderoth (1978) failed to find support for either model using the tilt aftereffect under four viewing conditions. Both models were criticised as being over simplistic although they only used the three class model of Moulden's (1974, 1980).

Moulden (1980) himself states that the model is unable to account for several findings eg. Noda, Creutzfeldt and Freeman (1971) found binocular neurones excited by stimulation to one eye but inhibited when stimulated by the other.

Both models assume transfer is dependent on binocular channels and that stereoblind individuals lack the normal complement of binocular neurones. Therefore, these individuals would be expected to show no transfer of visual aftereffects. This is discussed below.

14.4.3. Stereoscopic Vision and Evidence of Transfer

Percentage interocular transfer of visual aftereffects has been used as an index of the binocular integrity and function of visual cortical neurones (Hohmann and Creutzfeldt, 1975). Further support has been gained from the close association between stereoacuity and percentage transfer of tilt and adaptation aftereffects (Movshon et al, 1972; Mitchell and Ware, 1974).

Both models, the Lehmkuhle et al (1975b) and Moulden (1974, 1980) models, assume that individuals who are stereoblind possibly lack binocular neurones and therefore will show no transfer. However, the relationship between stereopsis and percentage interocular transfer has been established with only a few individuals (Hess, 1978) and this view would also suggest that transfer and stereopsis are mediated by the same neural substrate.

Hess (1978) reported that one stereoblind subject had normal levels of transfer of contrast threshold elevation although another failed to show any transfer but had a stereoacuity of 100" of arc. Wade (1976) reported that 11 subjects with a history of childhood strabismus but with both eyes binocularly aligned did show transfer of the movement aftereffect. Also, Anderson et al (1980) reported that six stereoblind subjects showed transfer of the threshold elevation of contrast (a result also reported by Lema and Blake, 1977). Transfer of visual aftereffects in stereoblind subjects have been reported in several studies; using the movement aftereffect (Mann, 1978) and tilt aftereffect (Movshon et al, 1972; Hohmann and Creutzfeldt, 1975; Maraini and Porta, 1978). Thus, transfer is reported for some stereoblind subjects suggesting some level of binocular interaction is retained, although the transfer is sometimes reduced relative to normal subject levels. Anderson et al (1980) reported that for stereoblind subjects who do not possess strabismus, the transfer is the same as that reported for normals.

Further, stereoblind subjects have shown other types of binocular interaction. Stereoblind subjects showed no evidence of binocular summation but did show inhibitory binocular interactions in a psychophysical study carried out by Levi, Harwerth and Smith (1979). Wolfe and Held (1979) reported near normal cyclotorsional responses to rotating patterns by stereoblind subjects which are dependent on binocular processes. It is possible that abnormal visual input selectively disrupts some binocular interactions leaving others intact making binocular oculomotor responses as above possible. Further support for this view comes from a recent study by Wolfe, Held and Bauer (1981) who reported normal OKN (optokinetic nystagmus) for stereoblind subjects in response to dynamic cyclopean stimulation. It would be of interest to measure interocular transfer levels in these subjects.

Evidence for selective disruption of binocular connections has been found in the neurophysiological literature. Abnormal visual input, ie. alternating monocular occlusion in the cat resulted in reduced proportions of binocular neurones in the cortex but not in the superior colliculus. These animals lacked stereoscopic vision (Gordon and Presson, 1977).

The failure to show transfer of an aftereffect cannot be assumed to reflect a lack of the normal complement of binocular neurones. Also, failure to show stereoscopic vision cannot be inferred to result from a lack of binocular connections. The very presence of suppression (Keck and Price, 1982) and fusion (Richards, 1970) in some stereoblind individuals indicates some form of binocular interaction is present. The transfer paradigm is perhaps not a good index of binocular function as these models and other authors have suggested.

Selby and Woodhouse (1981) suggested that the ratio of the contrast sensitivities of the two eyes may be a better indicator of binocular function than the presence or absence of interocular transfer. In a group of amblyopic subjects, at low spatial frequencies when the ratio was equal or low, transfer of threshold elevation of contrast occurred, when the contrast sensitivity ratio was high, transfer was reduced or absent.

The above studies suggest that stereopsis and transfer of visual aftereffects are not mediated by the same binocular channels. However, if an individual does possess some stereoscopic ability it is probable that there will be some interocular transfer of a visual aftereffect but, possession of transfer alone is not necessarily evidence that the individual will possess stereoscopic vision. Failure to find a good correlation between stereoacuity and percentage interocular transfer reported in chapter 13 for a group of binocularly normal subjects supports this conclusion.

14.4.4. Interocular Transfer Measures and Depth Discrimination Measures of Ocular Asymmetry

Greater transfer in one direction from the dominant to the non-dominant eye relative to the opposite direction may reflect a greater proportion of binocular neurones responsive to that eye or an increase in activity of the binocular neurones stimulated by that eye. The mechanism responsible for the increased magnitude of the aftereffect may also be responsible for the large disparity depth discrimination measures. Attenuation of the dominant eye by 1 log unit increased stereoscopic latencies for depth discriminations for large disparate displays above the non or both attenuated display conditions. This increase in latency was greater when the non-dominant eye was attenuated. If the proportion of binocular neurones sensitive to the dominant eye is greater than the proportion of neurones sensitive to the non-dominant eye and attenuated by 1 log unit, then the overall level of activity in these units may be reduced. However, the pooled activity of these units (dominant eye adapt and test) would still be greater than that for the binocular units responsive to the non-dominant eye and therefore, may account for the shorter reaction times relative to those for the attenuated condition of the non-dominant eye. Differential activity levels for the binocular units responsive to the two eyes may also explain the transfer results: greater transfer in one direction may reflect in terms of the transfer models either i) a greater proportion of binocular units responsive to that eye or ii) an increase in firing rate for these units.

However, the relation between the depth discrimination measures and the transfer measures was found for the large disparate displays only. Therefore, the binocular units involved must be responsive to large disparities. It was suggested that the large disparity depth discrimination measures of ocular asymmetry were related to the binocular centre that subserves fusional vergence movements or to the muscle outputs themselves that control vergence. It is possible that transfer is mediated by the same binocular units or substrate which reflect the same degree of asymmetry. If this is the case interocular transfer would not necessarily be indicative of the level of stereoscopic acuity. Wade reported (1976a) that 11 stereoblind subjects showed transfer of the movement aftereffect and these subjects also had binocularly aligned eyes. Binocular alignment may reflect an intact binocular system subserving vergence via which transfer is mediated.

14.5. Summary of Chapter 14 and Conclusions of Part IV.

In chapter 12 the spatial frequency shift was measured under five viewing conditions and a measure of ocular asymmetry was derived from the two transfer conditions. This measure positively correlated with the depth discrimination measures of ocular asymmetry. In chapter, 13 stereothresholds were measured for the same group of subjects as in the above experiment although high levels of transfer were not significantly related to good stereo-acuity. However, the results confirmed reports from other studies for binocular normal subjects (Mitchell et al, 1974, 1975). In chapter 14, these results were discussed in relation to two models of interocular transfer; the Lehmkuhle and Fox model (1975b) and the Moulden (1974, 1980) model. The predictions of the models for the aftereffect magnitudes under the different viewing conditions were outlined. One model (Lehmkuhle and Fox, 1975b) was unable to accommodate the asymmetries in transfer reported in chapter 12 for the spatial frequency shift. Results from two viewing conditions, monocular and binocular also failed to support this model.

Moulden's (1980) three and five class models could accommodate the results of transfer of the spatial frequency shift and the relation between the measures of ocular asymmetry derived from these results and the large disparity depth discrimination measures of ocular asymmetry if it is assumed that the binocular and monocular units have different levels of response or rates of saturation. However, it is not known what affects different rates of adaptation or the factors responsible for the different magnitudes of the aftereffects generated under the different viewing conditions other than the hypothesised differences in the proportions of the neuronal populations or differences in firing rates between them postulated in the models.

Several recent psychophysical and neurophysiological findings cannot be accounted for in the models. It was concluded that the transfer paradigm is not a good index of binocular function and integrity of the visual system as has been assumed, and recent studies on interocular transfer of visual aftereffects with stereoblind subjects are reviewed in support of this conclusion.

The close agreement of the transfer measures of ocular asymmetry and the large disparity depth discrimination measures indicate that both may share a common binocular process which is influenced by attenuation of 1 log unit and by adaptation to a patterned stimulus to result in equivalent asymmetry measures in two different procedures. It was suggested that the common binocular process is related to binocular vergence control.

PART V

CONCLUSIONS AND DISCUSSION

Chapter 15

Conclusions and Discussion

15.1. Techniques of Studying Ocular Asymmetries

The aim of the study was to investigate ocular dominance or ocular asymmetries using different binocular viewing situations. A review of the eye dominance literature revealed only a few studies that had used a binocular viewing approach to the study of ocular dominance. The majority of the eye dominance test were concerned with a comparison of the performance of one eye with the other. Eye dominance was considered to reflect a contest between the eyes and the nature of the tests and the dichotomous classification of the results supported this view. There were no reports of a systematic investigation of ocular dominance using binocular viewing situations, nor a measure that gave the degree of ocular dominance or asymmetry as well as the direction.

Binocular viewing was considered in this thesis to be an important approach to the study of ocular dominance or asymmetries in binocular vision. The experience of one visual world is achieved and maintained by the coordination of the two eyes. Ocular dominance cannot be considered independent of this interaction. The use of the term eye dominance suggests a contest between the images of the two eyes. The term ocular asymmetries has been adopted in this thesis to describe the asymmetries in binocular performance reported under the different viewing paradigms.

Ocular asymmetries have been reported in other studies that have used binocular viewing paradigms. However, the ocular asymmetry measures were an indirect observation of the main theme of investigation in these studies. Levelt (1965) and Legge and Rubin (1965) studied binocular luminance and binocular contrast matching respectively. Binocular matching in both studies did not obey the simple averaging rule and the binocular percept was influenced more by one eye than the other. Ono et al (1977) and Sheedy and Fry (1979) studied the visual directions of disparate images and reported that the direction of the binocular percept was not the strict average of the two directions specified by each eye's image. There was a slight shift of the "fused" image towards one eye which varied in degree between subjects. However, there was no systematic or detailed study of the above ocular asymmetry reports.

In this thesis, three different viewing paradigms have been used and one of these has not been adopted as a measure of ocular dominance or asymmetry before. First, a binocular rivalry procedure was used which can be considered to be one of the conventional tests of eye dominance. Second, a stereoscopic viewing procedure was adopted involving a depth discrimination task with selective attenuation of the displays to the two eyes. Third, interocular transfer of a visual aftereffect was studied. Measures of ocular asymmetry were derived from all three procedures. The main conclusions from the binocular visual approach to the study of ocular asymmetries are as follows:

1. Ocular asymmetries were reported with binocular viewing that reflect an asymmetry in performance towards one eye. In no situation was the binocular percept or was performance totally dependent upon one eye. An ocular asymmetry measure was derived from all three experimental procedures. This measure gave both the direction and the degree of asymmetry which varied continuously along a fixed interval scale.

2. In all three experimental paradigms viewing was dichoptic or binocular and the ocular asymmetry measures from the three procedures were positively related. The three viewing situations may be considered to involve different binocular interactions. Binocular rivalry is dependent on a competitive interaction between the images to the two eyes. Stereoscopic stimulation is dependent on the cooperative interaction or combination of the images to the two eyes and interocular transfer is considered to be mediated by hypothetical binocular units or neurones in the visual context.

3. The development of a quantitative measure of ocular asymmetry from binocular viewing paradigms mediated by different binocular interactions indicates that ocular asymmetries are a valid feature of binocular vision. Eye dominance as reported in the literature is partly a result of the nature of the tests used to measure it.

The sighting dominance measure reported in this thesis did not consistently relate to any of the ocular asymmetry measures.

4. Ocular asymmetry measures were derived from a conventional test of eye dominance, binocular rivalry. However, the range of the asymmetry measures was small and composites or combinations of the images to the two eyes composed a high percentage of the viewing time. These results further support the view that binocular vision is an interaction and integration of the eye's images and in some individuals the percept is influenced more by one eye than by the other.

5. A new approach and a new measure of ocular asymmetry has been developed using a stereoscopic viewing situation with selective attenuation of the displays. This was found to be a reliable and consistent measure of asymmetry.

6. This study has demonstrated that motor and sensory aspects to ocular dominance or asymmetries cannot be considered independent. Eye movements were implicated in all three measures of ocular asymmetry. In the binocular rivalry procedure it is possible that small eye movements may be responsible for the asymmetries in the durations each image was reported to be visible although it is not certain what influence such movements have on rivalry between afterimages. However, eye movements were not recorded in this study. It was hypothesised that the asymmetry may reside in the binocular centre or hypothesised binocular neurones that subserve vergence eye movements and/or the oculomotor system and not necessarily be in the motor system itself. The relationship between the ocular asymmetry scores from the rivalry and stereoscopic viewing procedures with the interocular transfer measures of ocular asymmetry support this view.

7. The work reported in this thesis suggests that ocular asymmetries can be considered as a variable in other studies on binocular vision or binocular interactions, for example in binocular summation or masking studies.

15.2. Relationship to other Dominance Studies

Several recent studies have reported that the sighting eye is related to the position of the egocentre (Barbeito, 1981; Ono and Barbeito, 1982) and the eye nearest the egocentre becomes the sighting eye. The position of the egocentre away from the midpoint between the two eyes was found to vary between individuals. The egocentre was not measured in this thesis and cannot be compared to the ocular asymmetry measures reported in this thesis. The sighting dominance results were mixed and not consistent over trials of the same test or between tests. The sighting results cannot be taken to indicate the direction of the egocentre from the midpoint.

Several studies have reported asymmetries in binocular vision where eye movements have been excluded (Ono et al, 1977; Sheedy and Fry, 1979; Legge and Rubin, 1981). The work reported in this thesis indicates that eye movements may be considered in the asymmetry measures. It is quite possible that asymmetries do occur in binocular vision exclusive of eye movements but this was not directly tested in this study.

15.3. Limitations of the Experimental Techniques

Small numbers of subjects participated in the experiments and the composition of the groups changed between experiments. A large group of subjects participating in all experiments would have provided a greater range of asymmetry scores and made direct comparisons between experiments easier.

In the binocular rivalry experiment, the degree of asymmetry decreased slightly with a change in the response categories available to the subject to record the appearance of the images. It is possible that the first procedure used, with no direct response for composites (Chapter 3) may have influenced the mode of responding and resulted in a possible response bias which would have influenced the ocular asymmetry measure. The response categories may have also directly influenced the appearance of the images (Swanston and Wade, 1981b). The changed procedure using different response categories was only carried out with real image rivalry and not with afterimage rivalry.

It was recognised that criterion free results could have been collected in the stereothreshold experiment if a true two alternative forced-choice procedure had been used.

15.4. Implications for Future Work

Several hypotheses have been proposed to explain the results reported in this thesis and in several cases these have not been tested directly. These hypotheses will be considered below in the light of further experiments that may be carried out.

Eye movements have been proposed as a factor underlying the ocular asymmetry measure derived from the real image rivalry experiments. These measures were significantly related to the ocular asymmetry measure derived from the afterimage experiment. This suggests that eye movements that influence the appearance of a rivalrous real image may have a similar effect on a rivalrous afterimage despite the lack of contour movement of the stimuli across the retinae with afterimage viewing. It is not clear how eye movements influence the duration of the visible appearance or disappearance of rivalrous afterimages. To investigate the eye movements associated with the visible phase of a rivalrous afterimage and real image, direct eye movement recordings could be made together with rivalry recordings by the subject. If an eye movement pattern was found to be associated with the visible phases of afterimages and real images it would suggest that contour movement across the retinae, that occurs with real image viewing, is not the only factor related to the visible appearance of an image.

Many of the studies on binocular rivalry have used small diameter stimuli in order to promote whole image rivalry. It would be interesting to compare the asymmetry measures derived from such rivalrous stimuli with the same stimuli when surrounded by either non-rivalrous stimuli and also by rivalrous stimuli. It is not known if these scores would change with the different surrounds or if the duration of perceived composites would increase. The rivalry measures were derived from the durations the images were reported to be visible. However, the categories of response provided by the experimenter have been found to influence the perceptual state of rivalrous images both in this work and in a study by Swanston and Wade (1981b). It would be interesting to record the durations of disappearance of the images using the same four categories of response especially for the afterimage experiment in which the alternations of the two images were not synchronous.

The ocular asymmetry measures derived from the depth discrimination experiment were hypothesised to reflect a difference in speed of processing of the signals from each eye arriving at the binocular site that control fusional vergence movements. Attenuation of the displays in the unequal luminance conditions would be expected to influence the stereoscopic latencies to make a depth judgement proportional to the level or value of attenuation. Alternatively, vergence eye movements could be monitored indirectly using a nonius line technique (Kidd, 1979). Initiation of vergence movements have been reported to be faster if the stereoscopic display has a monocularly visible feature. Brief presentation of nonius lines after the presentation of such a display would indicate if vergence movements were being made. The speed of processing hypothesis would suggest that increasing the attenuation of one display would increase the time taken to initiate and execute fusional vergence eye movements. Nonius lines briefly presented during the viewing of the stereograms with varying levels of unequal attenuation would indicate the speed of initiation of the vergence movements. It would be interesting to explore the latency or speed of processing hypothesis in the investigation of dichoptic and binocular masking with subjects with varying degrees of ocular asymmetry derived from the depth discrimination procedure reported in this study.

Legge and Rubin (1981) reported ocular asymmetry measures derived from a binocular contrast matching experiment using gratings presented at 180m seconds. The presentation time could be reduced to safely exclude eye movements and the resulting asymmetry scores could be compared to the ocular asymmetry scores derived from the depth discrimination procedure.

The different magnitudes of the spatial frequency shift were suggested to reflect different levels of adaptation as a possible result of differences in scanning rates or ranges between the eyes. Aftereffects can be generated with brief exposure durations of 18m seconds (Sekuler and Littlejohn, 1974). Interocular transfer of the spatial frequency shift experiment could be repeated using similar exposure durations and compared to the transferred aftereffect generated after prolonged viewing. A comparison of the ocular asymmetry scores derived from the two procedures would indicate if eye movements were involved in the ocular asymmetry measures derived from the two conditions of transfer.

The experimental work reported in this thesis presents a new approach to the study of ocular asymmetries in binocular vision. Several areas have not been pursued, e.g. egocentric directional judgements and the position of disparate images. However, this study has shown that ocular asymmetries are a valid feature of binocular vision and the depth discrimination procedure provides a quantitative measure of the degree and direction of this asymmetry. Ocular asymmetry can be considered as a variable in future investigations of binocular interactions. Further experiments are required to test the predictability of the ocular asymmetry measure for binocular visual performance and in the study of binocular interactions.

APPENDICES

APPENDIX A

Eye Dominance Tests Referred to in the Introduction, Chapter 1.

Ocular Dominance Tests Referred to in the Introduction.

Type of Dominance	Test	Description
	Manuscope	Subjects sight down a funnel designed by Parson (1924). See Fig 1.2, p 6.
	Manoptometer	Designed by Cuff (1930) and similar to above.
	Monoptometer	Movable rod fixed at one end. Ring on the rod is moved laterally in horizontal plane to line up with a distant disc (Lund, 1932). The eye that aligns the two is the dominant eye.
	Hole in the Card	Subject holds a card in front of eyes and sights through a small hole at a spot on the wall. The eye that sees the marker is the dominant eye (Crider, 1944).
1. SIGHTING DOMINANCE	Ring	Subject fixates a point , lifts up a ring to one eye and the eye chosen is the dominant eye (Crider, 1944).
	Box	Two threads, one at each end of a tube are aligned by the subject. The eye that aligns the two is the dominant eye (Gronwall and Sampson, 1974).
	Miles' A-B-C	Subject covers face with truncated cone and with both eyes open views a marker on the wall through the small aperture at the apex. The eye that sights is the dominant eye (Crider, 1944).
	Point	Subject aligns finger with a distant object. See text for description (Porta, 1593).

2. ACUITY DOMINANCE	Snellen chart	Visual acuity is measured for each eye. The eye with the higher acuity is the dominant eye.
3. RIVALRY (sensory) DOMINANCE	Binocular Rivalry	Subject views two different images one presented to each eye in a stereoscope arrangement eg. two different stamps, coloured stimuli, orthogonal gratings. The stimuli alternate in view and subject records this by alternating switch depressions. The eye whose image is reported to be visible for the longer total duration during the observation period is designated the dominant eye.

APPENDIX B

Analyses of Variance and Post-hoc Comparison Tests for the Binocular Rivalry Results with Real Images Reported in Part II, Chapter 3.

Table 3.1B Analysis of Variance for Real Image Binocular Rivalry Experiment: overall durations the images were visible during the inspection periods.

SOURCE	DF1	DF2	F	P VALUE	MEAN SQUARE	SUM OF S
DA	4	28	0.4912	0.7422	27.4544	109.817
TR	5	35	1.6102	0.1831	18.1845	90.922
BL	2	14	32.7024	0. **	289.4869	578.973
EY	1	7	3.5753	0.1005	1703.9843	1703.984
DA TR	20	140	0.9613	0.5123	8.5218	170.436
DA BL	8	56	1.2941	0.2655	8.7390	69.912
TR BL	10	70	1.1723	0.3242	7.8757	78.757
DA EY	4	28	0.6436	0.6359	130.3133	521.253
TR EY	5	35	1.2855	0.2923	6.5310	32.655
BL EY	2	14	0.0850	0.9190	0.7734	1.546
DA TR BL	40	280	1.2793	0.1314	7.5788	303.151
DA TR EY	20	140	1.1527	0.3048	6.6214	132.427
DA BL EY	8	56	0.9211	0.5062	9.2835	74.267
TR BL EY	10	70	1.2927	0.2517	6.7652	67.652
DA TR BL EY	40	280	1.2762	0.1337	8.0578	322.31
SS	7				570.3656	3992.55
SS DA	28				55.8974	1565.12
SS TR	35				11.2933	395.26
SS BL	14				8.8522	123.93
SS EY	7				476.5929	3336.15
SS DA TR	140				8.8650	1241.10
SS DA BL	56				6.7532	378.17
SS TR BL	70				6.7184	470.28
SS DA EY	28				202.4653	5669.02
SS TR EY	35				5.0807	177.82
SS BL EY	14				9.0965	127.35
SS DA TR BL	280				5.9242	1658.77
SS DA TR EY	140				5.7443	804.19
SS DA BL EY	56				10.0783	564.38
SS TR BL EY	70				5.2335	366.34
SS DA TR BL EY	280				6.3140	1767.90

** $f(2,14)\ 0.001 = 11.78$.

KEY

DA - Experimental Sessions.

TR - Trials 90 seconds each.

BL - 3 x 30 second inspection periods.

EY - Images to left and right eyes.

SS - Subjects.

DF - Degrees of freedom.

F - F value.

P VALUE - Probability value.

SUM OF SQ - Sum of square.

Table 3.2B Analysis of Variance for the Real Image Binocular Rivalry Experiment: duration of each switch depression or duration each image was visible.

SOURCE	DF1	DF2	F	P VALUE	MEAN SQUARE	SUM OF
DA	4	28	0.9047	0.4746	17.1437	68.57
TR	5	35	0.1898	0.9645	0.8308	4.15
BL	2	14	6.4192	0.0105 *	17.2473	34.49
EY	1	7	2.4674	0.1602	76.5475	76.54
DA TR	20	140	1.2048	0.2591	4.2886	85.77
DA BL	8	56	1.5690	0.1551	3.3431	26.74
TR BL	10	70	0.5771	0.8272	0.4843	4.84
DA EY	4	28	0.7598	0.5602	18.3826	73.53
TR EY	5	35	0.8959	0.4946	2.8852	14.42
BL EY	2	14	0.4796	0.6289	1.0801	2.16
DA TR BL	40	280	0.8903	0.6620	0.7293	29.17
DA TR EY	20	140	1.1132	0.3429	3.9879	79.75
DA BL EY	8	56	0.8685	0.5483	1.5850	12.68
TR BL EY	10	70	0.6052	0.8042	0.3122	3.12
DA TR BL EY	40	280	1.0283	0.4298	0.6958	27.83
SS	7				86.8486	607.94
SS DA	28				18.9494	530.58
SS TR	35				4.3776	153.21
SS BL	14				2.6868	37.61
SS EY	7				31.0237	217.16
SS DA TR	140				3.5597	498.35
SS DA BL	56				2.1308	119.32
SS TR BL	70				0.8392	58.74
SS DA EY	28				24.1928	677.39
SS TR EY	35				3.2203	112.71
SS BL EY	14				2.2522	31.53
SS DA TR BL	280				0.8191	229.34
SS DA TR EY	140				3.5824	501.52
SS DA BL EY	56				1.8250	102.20
SS TR BL EY	70				0.5158	36.10
SS DA TR BL EY	280				0.6766	189.45

* F (2,14) 0.025 = 4.86.

KEY

See Key on page 265.

Table 3.3B Analysis of Variance for the Real Image Binocular Rivalry Experiment: frequency of appearance of each image.

SOURCE	DF1	DF2	F	P VALUE	MEAN SQUARE	SUM OF
DA	4	28	1.2090	0.3291	76.0774	304.3
TR	5	35	2.2911	0.0667	51.3957	256.9
BL	2	14	1.2818	0.3082	29.3528	58.7
EY	1	7	0.0225	0.8851	0.3063	0.3
DA TR	20	140	1.5894	0.0631	19.9870	399.7
DA BL	8	56	2.0812	0.0530	30.1566	241.2
TR BL	10	70	1.0639	0.4015	12.2503	122.5
DA EY	4	28	1.2535	0.3115	11.6622	46.6
TR EY	5	35	1.3347	0.2726	11.5212	57.6
BL EY	2	14	0.3813	0.6899	4.9083	9.8
DA TR BL	40	280	1.0276	0.4310	12.2593	490.3
DA TR EY	20	140	1.0083	0.4565	9.2917	185.8
DA BL EY	8	56	1.2318	0.2980	11.9934	95.9
TR BL EY	10	70	1.1086	0.3682	9.3658	93.6
DA TR BL EY	40	280	0.9635	0.5377	8.6561	346.2
SS	7				985.5436	6898.8
SS DA	28				62.9262	1761.9
SS TR	35				22.4328	785.1
SS BL	14				22.9004	320.6
SS EY	7				13.6285	95.3
SS DA TR	140				12.5753	1760.5
SS DA BL	56				14.4899	811.4
SS TR BL	70				11.5150	806.0
SS DA EY	28				9.3038	260.5
SS TR EY	35				8.6320	302.1
SS BL EY	14				12.8734	180.2
SS DA TR BL	280				11.9300	3340.4
SS DA TR EY	140				9.2148	1290.0
SS DA BL EY	56				9.7363	545.2
SS TR BL EY	70				8.4481	591.3
SS DA TR BL EY	280				8.9840	2515.5

KEY

See Key on page 265.

Table 3.4B Post-hoc Comparisons using the Scheffé Test (Hays, 1963).

1). Overall mean durations each image is visible.

Source	Sum of Sq	DF	Mean Square	F	Significance
3 x 30 sec					
Inspection periods	578.97	2	289.48	32.70	0.00001
Errors	123.93	14	530.04		

Comparison: 0 - 30 vs 30 - 60 second inspection periods.

$$s = \frac{8.8522}{8x6x5x2} = 0.01844$$

$$S = 2 \times F0.01\ (2,14) = 17.72$$

$$S \times s = 0.32678$$

$$Ec = (1^2 + \tfrac{1}{2}^2 + \tfrac{1}{2}^2) = 1.5$$

$$Ec \times S \times s = 0.490$$

Comparison = 12.288 - 13.515 = 1.227^2 = 1.5055

Criterion < Comparison.

Therefore, the first 30 second inspection period is significantly shorter than the second at the 1% level.

2). Durations of each depression.

Source	Sum of Sq	Df	Mean Square	F	Significance
3 x 30 sec					
Inspection periods	34.4946	2	17.2473	6.4192	0.0105
Errors	37.6157	14	2.6868		

Comparison: 0 - 30 vs 30 - 60 second inspection periods.

$$s = \frac{2.6868}{8x5x6x2} = 0.0055975$$

$$S = 2 \times F\ 0.05\ (2,14) = 9.2$$

$$S \times s = 0.051497$$

$$Ec = (1^2 + \tfrac{1}{2}^2 + \tfrac{1}{2}^2) = 1.5$$

$$Ec \times S \times s = 0.0772$$

Comparison = $0.024^2 = 0.0873$

Criterion < Comparison.

Therefore, the difference is significant at the 5% level.

Table 3.5B Analysis of Variance for the Real Image Binocular Rivalry Experiment: ocular asymmetry scores.

Source	Sum of Sq	Df	Mean Square	F	Significance
DA	0.451769	4	0.112942	0.5788	Not Significant
TR	0.032986	5	0.006597	1.2279	Not Significant
DA x TR	0.143894	20	0.007195	1.1512	Not Significant
SS	2.993127	7	0.427590		
SS x DA	5.463351	28	0.195120		
SS x TR	0.188042	35	0.005373		
SS x DA x TR	0.874944	140	0.006250		
Total	10.148113	239			

APPENDIX C

Analyses of Variance for the Binocular Rivalry Results with Afterimages Reported in Part II, Chapter 4.

Table 4.1C Analysis of Variance for Afterimage Binocular Rivalry: overall durations the images were visible.

SOURCE	DF1	DF2	F	P VALUE	MEAN SQUARE	SUM OF
DA	2	14	1.2827	0.3079	64.3797	128.75
TR	5	35	1.0639	0.3968	20.1816	100.90
BL	1	7	10.3221	0.0148**	569.4204	569.42
EY	1	7	1.2491	0.3006	242.4516	242.45
DA TR	10	70	0.6972	0.7238	9.0722	90.72
DA BL	2	14	0.1887	0.8301	2.4899	4.97
TR BL	5	35	0.7515	0.5906	9.9830	49.91
DA EY	2	14	0.0284	0.9720	1.3389	2.67
TR EY	5	35	1.2075	0.3260	13.6760	68.38
BL EY	1	7	0.0002	0.9880	0.0198	0.01
DA TR BL	10	70	0.6494	0.7665	7.0580	70.58
DA TR EY	10	70	1.0646	0.4009	16.3833	163.83
DA BL EY	2	14	0.0611	0.9410	1.1016	2.20
TR BL EY	5	35	0.2962	0.9117	4.5468	22.73
DA TR BL EY	10	70	0.9778	0.4705	9.3034	93.03
SS	7				301.7173	2112.02
SS DA	14				50.1897	702.65
SS TR	35				18.9688	663.90
SS BL	7				55.1652	386.15
SS EY	7				194.0937	1358.65
SS DA TR	70				13.0123	910.85
SS DA BL	14				13.1964	184.74
SS TR BL	35				13.2835	464.92
SS DA EY	14				47.0952	659.33
SS TR EY	35				11.3259	396.40
SS BL EY	7				80.9245	566.47
SS DA TR BL	70				10.8690	760.82
SS DA TR EY	70				15.3891	1077.23
SS DA BL EY	14				18.0337	252.47
SS TR BL EY	35				15.3505	537.26
SS DA TR BL EY	70				9.5146	666.01

** F (1,17) 0.025 = 8.07.

KEY

See Key on page 265.

Table 4.2C Analysis of Variance for Afterimage Binocular Rivalry: Duration of each switch depression.

SOURCE	DF1	DF2	F	P VALUE	MEAN SQUARE	SUM OF S
DA	2	14	0.2595			
TR	5	35	1.1549	0.3506	5.6481	28.2405
BL	1	7	12.2918	0.0099**	384.9906	384.9906
EY	1	7	0.7845	0.4052	25.1428	25.1429
DA TR	10	70	1.2447	0.2789	7.3538	73.5381
DA BL	2	14	0.3617	0.7028	1.3689	2.7379
TR BL	5	35	2.0815	0.0911	6.3905	31.9526
DA EY	2	14	0.4594	0.6409	2.7185	5.4371
TR EY	5	35	1.3598	0.2630	3.8258	19.1292
BL EY	1	7	0.0090	0.9269	0.2309	0.2309
DA TR BL	10	70	1.1271	0.3550	5.1096	51.0958
DA TR EY	10	70	1.7333	0.0902	6.6257	66.2571
DA BL EY	2	14	1.0951	0.3615	2.7969	5.5938
TR BL EY	5	35	0.7362	0.6014	2.1099	10.5493
DA TR BL EY	10	70	1.1447	0.3428	3.2355	32.3545
SS	7				121.2541	848.7785
SS DA	14				8.1510	114.1142
SS TR	35				4.8905	171.1691
SS BL	7				31.3210	219.2470
SS EY	7				32.0501	224.3508
SS DA TR	70				5.9083	413.5819
SS DA BL	14				3.7846	52.9848
SS TR BL	35				3.0702	107.4556
SS DA EY	14				5.9181	82.8540
SS TR EY	35				2.8136	98.4772
SS BL EY	7				25.5657	178.9601
SS DA TR BL	70				4.5333	317.3299
SS DA TR EY	70				3.8225	267.5757
SS DA BL EY	14				2.5539	35.7548
SS TR BL EY	35				2.8658	100.3034
SS DA TR BL EY	70				2.8265	197.8572

** F (1,7) 0.01 = 12.25.

KEY

See Key on page 265.

Table 4.3C Analysis of Variance for Afterimage Binocular Rivalry: frequency of appearance of each image.

SOURCE	DF1	DF2	F	P VALUE	MEAN SQUARE	SUM OF
DA	2	14	4.6102	0.0290 *	15.6736	31.3
TR	5	35	0.9213	0.4788	2.0351	10.1
BL	1	7	39.3543	0.0004**	77.2934	77.2
EY	1	7	0.0159	0.9031	0.0434	0.0
DA TR	10	70	1.2582	0.2710	2.4944	24.9
DA BL	2	14	0.6791	0.5230	0.3611	0.7
TR BL	5	35	1.7041	0.1595	2.3184	11.5
DA EY	2	14	2.0548	0.1650	2.5278	5.0
TR EY	5	35	1.0592	0.3994	0.4684	2.3
BL EY	1	7	0.9937	0.3520	0.6267	0.6
DA TR BL	10	70	1.3317	0.2311	1.7236	17.2
DA TR EY	10	70	0.9548	0.4901	0.5528	5.5
DA BL EY	2	14	1.3339	0.2950	0.8403	1.6
TR BL EY	5	35	1.9978	0.1032	1.1934	5.9
DA TR BL EY	10	70	1.8747	0.0635	0.7569	7.5
SS	7				114.7636	803.3
SS DA	14				3.3998	47.5
SS TR	35				2.2089	77.3
SS BL	7				1.9640	13.7
SS EY	7				2.7220	19.0
SS DA TR	70				1.9825	138.7
SS DA BL	14				0.5317	7.4
SS TR BL	35				1.3605	47.6
SS DA EY	14				1.2302	17.2
SS TR EY	35				0.4422	15.4
SS BL EY	7				0.6307	4.4
SS DA TR BL	70				1.2942	90.5
SS DA TR EY	70				0.5790	40.5
SS DA BL EY	14				0.6300	8.8
SS TR BL EY	35				0.5974	20.9
SS DA TR BL EY	70				0.4038	28.2

* F (2,14) 0.05 = 3.34.

** F (1,7) 0.001 = 29.25.

Table 4.4C Analysis of Variance for Afterimage Binocular Rivalry: ocular asymmetry scores.

Source	Sum of Sq	Df	Mean Square	F	Significance
DA	0.165550	2	0.082775	2.3563	Not significant
TR	0.169174	5	0.033835	0.4357	Not significant
DA x TR	0.199849	10	0.019985	0.3709	Not significant
SS	2.296516	7	0.328074		
SS x DA	0.491808	14	0.035129		
SS x TR	2.718067	35	0.077659		
SS x DA x TR	3.771995	70	0.053886		
Total	9.812959	143			

APPENDIX D

Analyses of Variance and Post-hoc Comparison Tests for the Binocular Rivalry Results with Real Images using the Four Response Procedure as Reported in Part II, Chapter 6.

Table 6.1D Analysis of Variance for Real Image Binocular Rivalry using the Four Categories of Response: overall durations the images were visible in the inspection periods.

SOURCE	DF1	DF2	F	P VALUE	MEAN SQUARE	SUM OF
TR	5	35	0.8853	0.5012	2.2686	11.34
BL	2	14	4.1708	0.0379 *	33.7405	67.48
CD	3	21	28.8795	0. **	2972.0346	8916.10
TR BL	10	70	0.8510	0.5821	2.0182	20.18
TR CD	15	105	0.5954	0.8726	6.8168	102.25
BL CD	6	42	0.8072	0.5701	16.6153	99.69
TR BL CD	30	210	0.9232	0.5857	5.9568	178.70
SS	7				16.9879	118.91
SS TR	35				2.5624	89.68
SS BL	14				8.0897	113.25
SS CD	21				102.9114	2161.13
SS TR BL	70				2.3716	166.01
SS TR CD	105				11.4484	1202.08
SS BL CD	42				20.5839	864.52
SS TR BL CD	210				6.4524	1354.99

* F (2,14) 0.05 = 3.74.

** F (3,21) 0.001 = 8.10.

KEY

CD = Four categories of response.

See Key on page 265.

Table 6.2D Analysis of Variance for the Real Image Binocular Rivalry using the Four Response Categories: duration of each switch depression.

SOURCE	DF1	DF2	F	P VALUE	MEAN SQUARE	SUM OF S
TR	5	35	1.0183	0.4218	2.5201	12.600
BL	2	14	0.6939	0.5160	1.0834	2.166
CD	3	21	5.1084	0.0082**	31.5972	94.791
TR BL	10	70	1.0067	0.4466	2.0859	20.858
TR CD	15	105	0.8202	0.6533	1.9525	29.287
BL CD	6	42	1.4004	0.2371	9.2490	55.494
TR BL CD	30	210	0.9559	0.5370	2.0273	60.818
SS	7				20.0654	140.457
SS TR	35				2.4749	86.622
SS BL	14				1.5612	21.856
SS CD	21				6.1853	129.891
SS TR BL	70				2.0719	145.035
SS TR CD	105				2.3806	249.963
SS BL CD	42				6.6046	277.393
SS TR BL CD	210				2.1208	445.377

** F (3,21) 0.01 = 4.87.

KEY

CD = Four categories of response.

See Key on page 265.

Table 6.3D Post-hoc Comparisons using the Scheffé Test (Hays, 1963).

1). Overall mean durations for each of the four response categories.

Source	Sum of Sq	Df	Mean Square	F	Significance
Response Categories	8916.1038	3	2972.0346	28.8795	0.00001
Error	2161.1399	21	102.9114		

a) Comparison: Left and Right Eye Image vs Composites and "Total disappearances".

$$s = \frac{102.9114}{8 \times 6 \times 3} = 0.7146625$$

$$S = 3 \times F\ 0.01\ (3,21) = 14.61$$

$$S \times s = 10.44$$

$$Ec = (\tfrac{1}{2}^2 + \tfrac{1}{2}^2 + \tfrac{1}{2}^2 + \tfrac{1}{2}^2) = 1$$

$$Ec \times S \times s = 10.44$$

Comparison = $10.459 - 3.792 = 6.667^2 = 44.449$

Criterion < Comparison.

Therefore, the difference is significant at the 1% level.

b) Comparison: Left Eye's Image vs Right Eye's Image.

$$s = 0.714662$$

$$S = 3 \times F\ 0.05\ (3,21) = 9.21$$

$$Ec = (1^2 + 1^2) = 1$$

$$Ec \times S \times s = 6.5820$$

Comparison = 0.068644

Criterion > Comparison.

Therefore, the difference is not significant.

(continued).

2). Mean duration of each switch depression.

Source	Sum of Sq	Df	Mean Square	F	Significance
Response Categories	94.7916	3	31.5972	5.1084	0.0082
Error	129.8913	21	6.1853		

Comparison: Left Eye's Image and Right Eye's Image vs Composites and "Total disappearances"

$$s = \frac{6.1853}{8x6x3} = 0.04295$$

$$S = 3 \times F\ 0.05\ (3,21) = 9.21$$

$$S \times s = 0.39560$$

$$Ec = (\tfrac{1}{2}^2 + \tfrac{1}{2}^2 + \tfrac{1}{2}^2 + \tfrac{1}{2}^2) = 1$$

$$Ec \times S \times s = 0.39560$$

Comparison = $0.758^2 = 0.574564$

Criterion < Comparison.

Therfore the difference is significant at the 5% level.

Table 6.4D Analysis of Variance for the Real Image Binocular Rivalry Experiment using the Four Categories of Response: frequency of appearance.

SOURCE	DF1	DF2	F	P VALUE	MEAN SQUARE	SUM OF SQ
TR	5	35	0.7364	0.6012	7.1115	35.5573
BL	2	14	3.9008	0.0450 *	47.9115	95.8229
CD	3	21	46.9204	0. **	2926.9878	8780.9635
TR BL	10	70	1.9813	0.0484	8.9760	89.7604
TR CD	15	105	0.5658	0.8948	1.1115	16.6719
BL CD	6	42	4.3046	0.0018	9.2587	55.5521
TR BL CD	30	210	23.0983	0. **	4.5760	137.2813
SS	7				339.1426	2373.9983
SS TR	35				9.6575	338.0122
SS BL	14				12.2825	171.9549
SS CD	21				62.3820	1310.0226
SS TR BL	70				4.5304	317.1285
SS TR CD	105				1.9644	206.2587
SS BL CD	42				2.1509	90.3368
SS TR BL CD	210				1.4770	310.1632

* F (2,14) 0.05 = 3.73.

** F (3,21) 0.001 = 8.10.

KEY

CD = Four response categories.

See Key on page 265.

APPENDIX E

Analyses of Variance and Planned Comparison Tests for the Depth Discrimination Experiment with Large (24'/28' of arc) and Small Disparities (12'/16' of arc) Reported in Part III, Chapter 9.

Table 9.1E Analysis of Variance for the Depth Discrimination Experiment with Large Disparities of 24' and 28' of arc.

Source	Sum of Sq	Df	Mean Square	F	Significance
Conditions of Selective Att.	1900.6640	3	633.5547	4.5803	0.0128 **
Trials	275.6889	9	30.6321	1.1659	0.3322 ns
Cond. x Trials	612.1350	27	22.6717	0.8555	0.6741 ns
Subjects	5813.8246	7	830.5464		
SS x Cond.	2904.7686	21	138.3223		
SS x Trials	1655.2711	63	26.2741		
SS x TR x Cond.	5008.8799	189	26.5020		

** $F\ (3,21)\ 0.025 = 3.86$.

Table 9.2E Summary Table for Planned Comparisons between the Mean Stereoscopic Latencies for the Large Disparity Stereograms (24'/28' of arc) under the Four Conditions of Selective Attenuation.

Source	Sum of Sq	Df	Mean Square	F	Significance
Conditions of Attenuation:		3			
N + B vs LE + RE	1760.4385	1	1760.4385	12.727	0.005
N vs B	133.6636	1	133.6636	0.966	NS
LE vs RE	6.724	1	6.724	0.049	NS
Errors		21	138.3223		

$F\ (1,21)\ 0.01 = 5.85$.

Conditions of Attenuation

N = Neither display attenuated.

B = Both displays attenuated.

LE = Left display attenuated.

RE = Right display attenuated.

Table 9.3E Analysis of Variance for the Depth Discrimination Experiment with Small Disparities of 12'/16' of arc.

Source	Sum of Sq	Df	Mean Square	F	Significance
Conditions of					
Attenuation	58.2172	3	19.4057	2.4040	NS
Trials	32.2174	9	3.5797	0.9799	NS
Cond. x Trials	58.6076	27	2.1707	0.9234	NS
Subject	2197.3085	7	313.9012		
SS x Cond.	169.5193	21	8.0723		
SS x Trials	230.1393	63	3.6530		
SS x Cond. x Tr.	444.2890	189	2.3507		

NS = Not significant.

Table 9.4E Analysis of Variance for the Depth Discrimination Experiment with Small Disparities of 12'/16' of arc: a replication experiment with 7 subjects.

Source	Sum of Sq	Df	Mean Square	F	Significance
Conditions of					
Attenuation	168.490165	3	56.163388	2.3004	NS
Trials	72.984830	9	8.109426	0.7424	NS
Cond. x Trials	299.557459	27	11.094721	1.2171	NS
Subjects	1388.726351	6	231.454392		
SS x Cond.	439.455844	18	24.414214		
SS x Trails	589.838270	54	10.922931		
SS x Cond. x Tr.	1476.740325	162	9.115681		

Table 9.5E Analysis of Variance for the Depth Discrimination Experiment with Large Disparities of 24' and 28' of arc: a replication experiment.

Source	Sum of Sq	Df	Mean Square	F	Significance
Conditions of Attenuation	4140.127759	3	1380.042586	8.6828	0.01 **
Trials	632.489167	9	70.276574	1.4460	NS
Cond. x Trials	1238.786216	27	45.880971	1.2427	NS
Subjects	5228.529891	6	871.421649		
SS x Cond.	2860.912072	18	158.939560		
SS x Trials	2624.434969	54	48.600648		
SS x Cond. x Tr.	5980.951034	164	36.919451		

** F (3,18) 0.01 = 5.09

Table 9.6E Summary Table for the Planned Comparisons between the mean Stereoscopic Latencies for the Four Conditions of Selective Attenuation (7 subjects) for the Large Disparity Stereograms (24'/28' of arc).

Source	Sum of Sq	Df	Mean Square	F	Significance
Conditions of Attenuation:					
N + B vs LE + RE	2022.34	1	2022.34	12.72	0.01 **
LE vs RE	1732.05	1	1732.05	10.90	0.01 **
N vs B	385.76	1	385.76	2.43	NS
Errors		18	158.94		

** F (1,18) 0.01 = 8.28.

APPENDIX F

Analyses of Variance and Planned Comparison Tests for the Depth Discrimination Experiment for Large (24'/28' of arc) and Small (8'/12' of arc) Disparity "Unscrambled" and "Scrambled" Stereograms Reported in Part III, Chapter 10.

Table 10.1F Analysis of Variance for the Depth Discrimination Experiment using Small Disparity "Scrambled" Stereograms (8'/12' of arc).

Source	Sum of Sq	Df	Mean Square	F	Significance
Conditions of Attenuation	375.6039	3	125.2013	3.3161	0.05 *
Trials	405.3609	9	45.0401	1.5515	NS
Cond. x Trials	470.2012	27	17.4149	0.5412	NS
Subjects	1763.0845	6	293.8474		
SS x Cond.	679.5970	18	37.7554		
SS x Trials	1567.6103	54	29.0298		
SS x Cond. x Tr.	5212.8257	162	32.1779		

* $F(3,18)\ 0.05 = 3.16$.

Table 10.2F Summary Table for the Planned Comparisons between the Mean Stereoscopic Latencies for the Four Conditions of Selective Attenuation for the Small Disparity "Scrambled" Stereograms (8'/12' of arc).

Source	Sum of Sq	Df	Mean Square	F	Significance
Conditions of Attenuation:					
N + B vs LE + RE	122.62	1	122.62	3.25	NS
LE vs RE	252.70	1	252.70	6.65	*
N vs B	0.21	1	0.21	0.006	NS

* $p < 0.05$

$F\ (1,18)\ 0.05 = 4.41$.

Table 10.3F Analysis of Variance for the Depth Discrimination Experiments using Large Disparity "Scrambled" Stereograms (24'/28' of arc).

Source	Sum of Sq	Df	Mean Square	F	Significance
Conditions of Attenuation.	2213.9454	3	737.9818	4.4012	0.025
Trials	409.2582	9	45.4731	0.9221	NS
Cond. x Trials	812.4185	27	30.0896	0.6123	NS
Subjects	6023.0060	6	1003.8343		
SS x Cond.	3018.1974	18	167.6776		
SS x Trials	2663.0120	54	49.3150		
SS x Cond. x Tr.	7961.3410	162	49.1441		

$F\ (3,18)\ 0.025 = 3.95$.

Table 10.4F Summary Table for the Planned Comparisons between the Mean Stereoscopic Latencies for the Four Conditions of Selective Attenuation for Large Disparity "Scrambled" Stereograms (24'/28' of arc).

Source	Sum of Sq	DF	Mean Square	F	Significance
Conditions of Attenuation:					
N + B vs LE + RE	1489.58	1	1489.58	8.88	**
LE vs RE	259.52	1	259.52	1.55	NS
N vs B	465.01	1	465.01	2.77	NS
Errors		18	167.6776		

** $p < 0.01$.

$F\ (1,18)\ 0.01 = 8.28$.

Table 10.5F Analysis of Variance for the Depth Discrimination Experiments for the Four Sessions with Large, Small, "Scrambled" and "Unscrambled" Displays (7 Subjects).

Source	Sum of Sq	Df	Mean Square	F	P
SCRAM/UNSCRAM	1242.7258	1.	1242.7258	5.8008	0.0527
DISPARITIES - SM/LG.	5819.3263	1	5819.3263	15.7469	0.0074 **
TRIALS	254.7355	9	28.3039	0.8688	0.5582
CONDITIONS	4644.2427	3	1548.0809	8.3815	0.0011 **
SCRAM/UNSCRAM x DISP	33.4530	1	33.4530	0.0612	0.8128
SCRAM/UNSCRAM x TRIALS	401.6163	9	44.6240	1.1967	0.3163
DISPARITY x TRIALS	539.7927	9	59.9770	1.4656	0.1845
SCRAM/UNSCRAM x CONDITIONS	69.5379	3	23.1793	0.3833	0.7663
DISPARITY x CONDITIONS	1819.7937	3	606.5979	6.1495	0.0046 **
TRIALS x CONDITIONS	718.7173	27	26.6192	0.8062	0.7393
SCRAM x DISP x TRIALS	323.6852	9	35.9650	1.3279	0.2447
SCRAM x DISP x CONDS.	364.5306	3	121.5102	2.7017	0.0762
SCRAM x TRIALS x CONDS.	960.2913	27	35.5663	1.1877	0.2530
DISP x TRIALS x CONDS.	510.2270	27	18.8973	0.6145	0.9314
SCRAM x DISP x TRIALS x CONDS.	631.8834	27	23.4031	0.6957	0.8659
SUBJECTS	7621.4405	6	1270.2401		
SSxSC	1285.4006	6	214.2334		
SSxDP	2217.3251	6	369.5542		
SSxTR	1759.1458	54	32.5768		
SSxCD	3324.6485	18	184.7027		
SSxSCxDP	3278.8998	6	546.4833		
SSxSCxTR	2013.6463	54	37.2897		
SSxDPxTR	2209.8261	54	40.9227		
SSxSCxCD	1088.4331	18	60.4685		
SSxDPxCD	1775.5517	18	98.6418		
SSxTRxCD	5348.8448	162	33.0176		
SSxSCxDPxTR	1462.5347	54	27.0840		
SSxSCxDPxCD	909.5564	18	44.9754		
SSxSCxTRxCD	4851.2718	162	29.9461		
SSxDPxTRxCD	4981.9242	162	30.7526		
SSxSCxDPxTRxCD	5449.8050	162	33.6408		

** F (1,6) 0.01 13.74, F (3,18) 0.01 = 5.09.

Table 10.6F Analysis of Variance for the Depth Discrimination Experiment with the Random Sequence of Trials of Small, Large, "Scrambled" and "Unscrambled" Stereograms (20 Subjects).

Source	Sum of Sq	Df	Mean Square	F	P
DISPARITIES - SM/LG.	15223.3228	1	15223.3228	68.3758	0.0001 **
SCRAM/UNSCRAM	14768.2755	1	14768.2755	76.9393	0.0001 **
CONDITIONS	1379.0287	3	459.6762	7.5826	0.0002 **
TRIALS	72.9154	3	24.3051	0.5501	0.6502
DISP x SCRAM/UNSCRAM	3660.4742	1	3660.4742	45.3739	0.0001 **
D. CONDITIONS	1032.1865	3	344.0622	9.2474	0.0001 **
SC CONDITIONS	781.4974	3	260.4991	6.3959	0.0008 **
DP TRIALS	103.3776	3	34.4592	1.3129	0.2791
SC TRIALS	182.9435	3	60.9812	2.9203	0.0417 *
CD TRIALS	185.6994	9	20.6333	0.9655	0.4704
DP SC COND.	419.1148	3	139.7049	3.7986	0.0149 **
DP SC TRIALS	161.6844	3	53.8948	2.9617	0.0397 *
DP CD TRIALS	103.3701	9	11.4856	0.5745	0.8168
SC CD TRIALS	146.6741	9	16.2971	0.8337	0.5860
DP SC CD TRIALS	129.5637	9	14.3960	0.7795	0.6356
SUBJECTS	25166.5308	19	1324.5543		
SSxDP	4230.1981	19	222.6420		
SSxSC	3646.9957	19	191.9471		
SSxCD	3453.2088	57	60.5826		
SSxTR	2518.6348	57	44.1866		
SSxDPxSC	1532.7984	19	80.6736		
SSxDPxCD	2120.7665	57	37.2064		
SSxSCxCD	2321.5432	57	40.7288		
SSxDPxTR	1496.0270	57	26.2461		
SSxSCxTR	1190.2637	57	20.8818		
SSxCDxTR	3654.1829	171	21.3695		
SSxDPxSCxCD	2096.3463	57	36.7780		
SSxDPxSCxTR	1037.2540	57	18.1974		
SSxDPxCDxTR	3418.6132	171	19.9919		
SSxSCxCDxTR	3342.7720	171	19.5484		
SSxDPxSCxCDxTR	3158.0675	171	18.4682		

* F (3,57) 0.05 = 2.76.

** F (1,19) 0.001 = 15.38, F (3,57) 0.001 = 6.17, F (3,57) = 3.34.

Table 10.7F Statistical Test, the t-test used for Post-hoc Comparisons between the overall Mean Stereoscopic Latencies for 2 and 3-way Interactions.

$$t = \frac{Xa - Xb}{\sqrt{MSe\left(\frac{1}{na} + \frac{1}{nb}\right)}}$$

$$MSe = \frac{SSe.Va1 + SSe.Va1 \times Va2}{Df\ pooled}$$

$$Df = \frac{(MSe.Va1 + MSe.Va1 \times Va2)^2}{\frac{MSe.Va^2}{Df} \times \frac{MSe.Va1 \times Va2^2}{Df}}$$

Xa = mean of one level of variable a.

Xb = mean of one level of variable b.

Va1 = the levels of a variable which are being compared.

Va2 = second variable of the two-way interaction.

MSe = mean square error.

SSe = sum of square error.

Df = degrees of freedom.

na = number of observations for the mean value of a.

nb = number of observations for the mean value of b.

Table 10.8F Comparisons between the Mean Stereoscopic Latencies for the "Scrambled" and "Unscrambled" Displays for the Two Levels of Disparity using the t-test.

1). Comparison: Small Disparity Displays, "Scrambled" vs "Unscrambled".

$$\text{Comparison} = 6.776 - 3.365$$

$$\text{MSe} = \frac{3646.9957 + 1532.7984}{19 + 19} = 136.3104$$

$$t = \frac{3.411}{\sqrt{136.3104 \times (\frac{1}{320} + \frac{1}{320})}}$$

$$= 3.70$$

$$\text{Df} = \frac{(191.9475 + 80.6736)^2}{\frac{191.9475^2}{19} + \frac{80.6736^2}{19}} = 33$$

t 0.005, Df 30 = 2.75 (1-tailed test).

Therefore, latencies for the small disparity "scrambled" display are significantly longer than the equivalent "unscrambled" displays.

2). Comparison: Large Disparity Displays, "Scrambled" vs "Unscrambled".

$$\text{Comparison} = 17.056 - 6.8800$$

$$\text{MSe} = 136.3104$$

$$t = \frac{10.176}{0.923}$$

$$= 10.43$$

t 0.0005, Df 30 = 3.646 (1-tailed test).

Therefore, latencies for the large disparity "scrambled" displays are longer than those for the equivalent "unscrambled" displays

Table 10.9F Comparisons between the Mean Stereoscopic Latencies for Unequal and Equal Luminance Conditions for the Two Levels of Diparity using the t-test.

1). Comparison: Large Disparity Displays, Unequal vs Equal Luminance.

$$\text{Comparison} = 13.84 - 10.095$$

$$\text{MSe} = \frac{3453.2088 + 2120.7665}{57 + 57} = 48.89$$

$$t = \frac{3.745}{\sqrt{48.89 \times \left(\frac{1}{320} + \frac{1}{320}\right)}}$$

$$= 6.77$$

$$\text{Df} = \frac{(60.5826 + 37.2064)^2}{\frac{60.5826^2}{57} + \frac{37.2064^2}{57}} = 108$$

t 0.0005, Df 100 = 3.373 (1-tailed test).

Therefore, the latencies for the unequal luminance condition are significantly longer than the equal luminance condition at the 0.05% level.

2). Comparison: Small Disparity Displays, Unequal vs Equal Luminance.

$$\text{Comparison} = 5.18 - 5.294$$

$$\text{MSe} = 48.89$$

$$t = \frac{-0.114}{0.5528}$$

$$= -0.206$$

$$\text{Df} = 108$$

t 0.05, Df 100 = 1.658 (1-tailed test).

Therefore, there is no significant difference between these two conditions of display luminance.

Table 10.10F Comparisons between the Mean Stereoscopic Latencies for the 3-way Interaction for the Experimental Conditions of Selective Attenuation for the Two Levels of Disparity and Two Types of Display ("Scrambled"/"Unscrambled").

1). Comparison: Small Disparity "Unscrambled" Displays, Unequal vs Equal Luminance.

Comparison = 3.45 - 3.28

$$MSe = \frac{3453.2088 + 2096.3463}{57 \qquad 57} = 48.68$$

$$t = \frac{0.17}{0.78}$$

$$= 0.22$$

$$Df = \frac{(60.5826 + 36.778)^2}{\dfrac{60.5826^2}{57} + \dfrac{36.778^2}{57}} = 108$$

t 0.05, Df 120 = 1.645.

Therefore, there is no significant difference between the conditions.

2). Comparison: Small Disparity "Scrambled" Displays, Unequal vs Equal Luminance.

Comparison = 6.91 -6.13

$$t = 1.00$$

$$Df = 108$$

t 0.05, Df 120 = 1.645.

Therefore, the difference in the two conditions is not significant.

(continued).

3). Comparison: Large Disparity "Unscrambled" Displays, Unequal vs Equal Luminance.

Comparison = 7.58 - 6.18

t = 1.80

Df = 108

t 0.05, Df 120 = 1.645 (1-tailed test).

Therefore, there is a significant increase in the stereoscopic latencies from the equal to the unequal luminance of the displays at the 5% level.

4). Comparison: Large Disparity "Scrambled" Displays, Unequal vs Equal Luminance.

Comparison = 20.10 - 14.01

t = 7.80

Df = 108

t 0.0005 Df 120 = 3.373 (1-tailed test).

Therefore, there is a significant increase in the mean stereoscopic latencies from the equal to the unequal luminance conditions of the displays at the 0.05% level.

Table 10.11F Measures of Ocular Asymmetry for a group of subjects (N=8) drawn from several depth discrimination experiments for a comparison between two presentation procedures; a) block presentation, 40 trials (see chapter 9) and b) random presentation over 64 trials(see chapter 10).

i) Large Disparity "Unscrambled" Display Measures (24'/28' of arc).

Subjects:	a) Block Presentation (10 trials in each condition).	b) Random Presentation (4 trials in each condition).
SC	0.06	-0.06
EB	-0.09	-0.004
SM	0.30	0.14
SK	0.41	0.42
DG	0.22	-0.02
SW	0.30	0.17
EC	0.18	0.52
AL	-0.04	-0.16

Correlation coefficient of a) with b) $r = 0.64$, $p < 0.05$ (1-tailed test).

ii) Small Disparity "Unscrambled" Displays (8'/12' or 12'/16' of arc).

Subjects:	a) Block Presentation (as above)	b) Random Presentation (as above)
SC	0.05	-0.003
EB	-0.43	0.08
SM	0.001	0.12
SK	-0.13	0.02
DG	0.20	-0.61
SW	-0.12	0.02
EC	-0.02	0.29
AL	0.02	-0.05

Correlation coefficient of a) with b) = -0.52, not significant.

APPENDIX G

Ocular Asymmetry Scores for 9 Subjects Derived from the Depth Discrimination Experiments and Chi Squared Values for the T-Scope Experiment Reported in Part III, Chapter 11.

Table 11.1G Ocular Asymmetry Scores for 9 subjects derived from the Depth Discrimination Experiments (1) with Small Disparate "Unscrambled" Displays, b) Small Disparate "Scrambled" Displays, c) Large Disparate "Unscrambled" Displays and d) Large Disparate "Scrambled" Displays.

Disparity:	Small 8'/12' or 12'/16'		Large 24'/28' of arc	
Type of Display.	"Unscrambled"	"Scrambled"	"Unscrambled"	"Scrambled"
Subjects:				
SC	+0.05	+0.10	+0.06	+0.32
EB	-0.43	+0.05	-0.09	-0.21
SM	+0.001	+0.05	+0.30	-0.10
SK	-0.13	+0.06	+0.41	+0.09
EM	-0.04	-0.17	-0.37	-0.07
SW	-0.12	-0.02	+0.30	+0.17
DM	-0.05	-0.05	-0.14	+0.25
EC	-0.02	+0.13	+0.18	+0.49
AC	+0.02	-0.19	-0.04	-0.11
MEANS (ignoring the sign)	0.096	0.091	0.21	0.20

(1)The dominance scores for the 6 subjects have been taken from experiments reported in the thesis, these are EB, EM, DM, SK, SW and SM.

These measures of ocular asymmetry derived from the depth discrimination experiments were correlated with the ocular asymmetry measures derived from the binocular rivalry procedure (see table 11.1G) and the results are as follows:

1. The correlation coefficient for the binocular rivalry and the small disparity "unscrambled" measures is $r = 0.41$, which is not significant.

2. The correlation coefficient for the binocular rivalry and the small disparity "scrambled" measures is $r = 0.57$, which is not significant.

3. The correlation coefficient for the binocular rivalry and the large disparity "unscrambled" measures is $r = 0.59$, which is significant at the 5% level (1-tailed test).

4. The correlation coefficient for the binocular rivalry and the large disparity "scrambled" measures is $r = -0.01$,which is not significant.

Table 11.2G Chi-squared values for each subject for the frequency distribution of the correct depth discriminations under the four conditions of selective attenuation.

Subjects:	X value	Significance
SC	1.82	NS
EB	4.30	NS
SM	3.21	NS
EM	7.74	NS
SW	4.08	NS
DM	7.68	NS
EC	1.74	NS
AC	3.23	NS

X 0.05, df, 3 = 7.815.

NS = Not Significant.

APPENDIX H

Mean Stereoscopic Latencies for the Depth Discrimination Experiments with Small and Large Disparate Displays under the Four Conditions of Selective Attenuation. Analysis of Variance for the Interocular Transfer Results for the Five Viewing Conditions and Post-hoc Comparison Tests. Ocular Asymmetry Scores from the Normalised Transfer Data.

Table 12.1H Mean Stereoscopic Latencies (seconds) and standard deviations (SD) for Each Subject to Make a Depth Judgement between Two Squares (24'/28' of arc disparity) under Four Conditions of Selective Attenuation.

	Attenuation Conditions			
	Neither Display	Both Displays	Left Display	Right Display
Subjects:				
EB	8.122	11.204	12.763	10.574
SW	0.901	2.406	1.473	2.714
SK	7.406	8.196	7.209	6.842
SM	2.403	2.645	3.669	8.786
DM	2.523	5.189	11.697	4.623
PR	7.423	5.576	5.415	4.403
EM	2.954	4.711	9.467	4.403
PC	6.493	16.865	28.759	12.176
MEAN	4.775	7.099	10.056	8.435

Table 12.2H Mean Stereoscopic Latencies (seconds) and standard deviations (SD) for Each Subject to Make a Judgement between Two Squares (12'/16' of arc) under Four Conditions of Selective Attenuation.

	Attenuation Conditions			
	Neither Display	Both Displays	Left Display	Right Display
Subjects:				
EB	8.455	8.954	10.592	4.182
SW	0.980	1.339	1.308	1.024
SK	7.925	12.395	9.256	7.188
SM	1.652	1.485	1.726	1.730
DM	2.387	9.462	9.103	8.172
PR	2.539	5.250	3.255	1.351
EM	1.792	1.767	2.076	1.918
PC	1.061	1.018	1.282	0.927
MEAN	3.350	5.210	4.820	3.310

Graph to Show the Potentiometer Readings and Corresponding Spatial Frequency Ratios of the Top to Bottom Gratings of the Test Display.

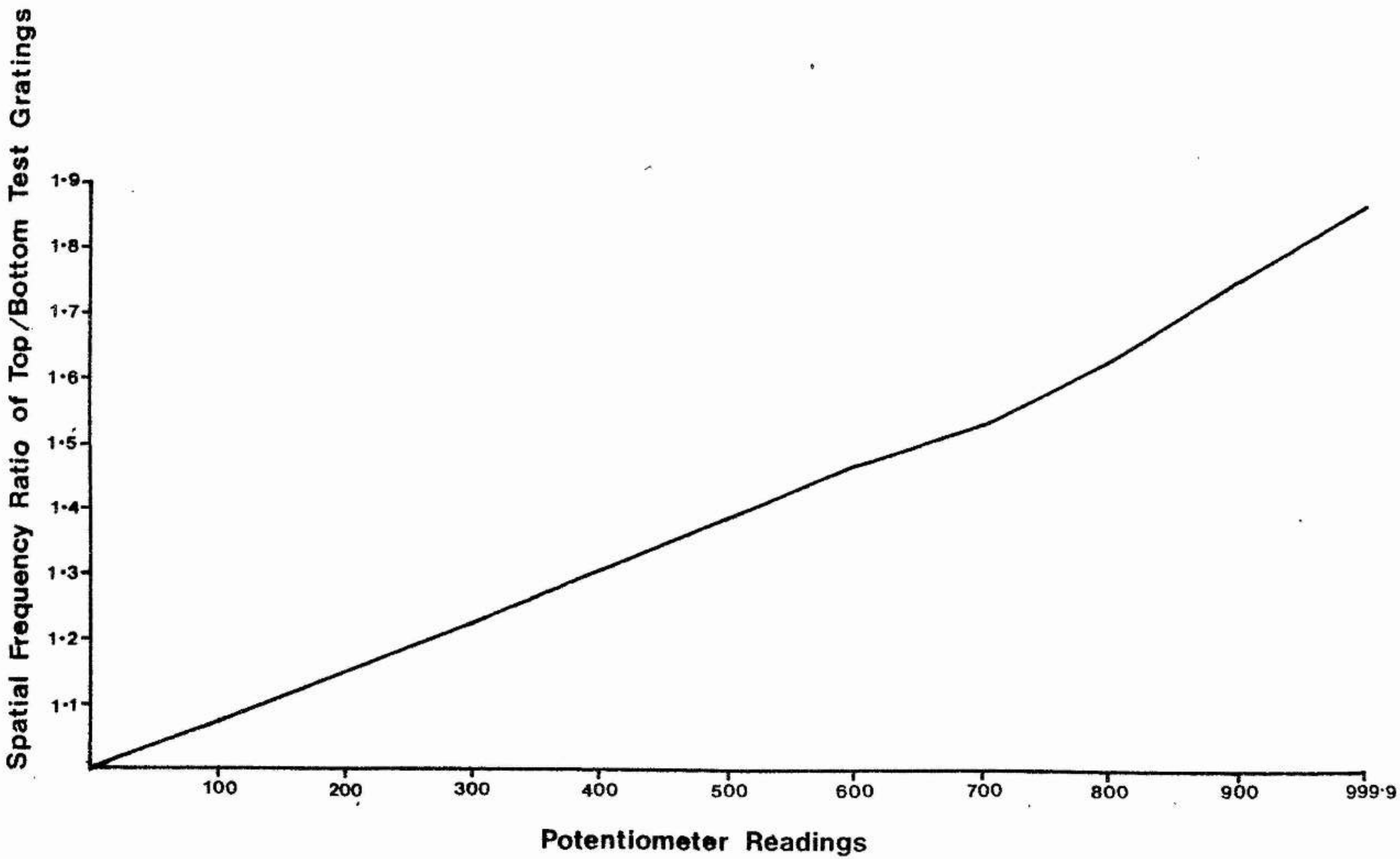


Table 12.3H Analysis of Variance for the Interocular Transfer Experiment for the Five Conditions of Viewing.

SOURCE	DF1	DF2	F	F VALUE	MEAN SQUARE	SUM OF SQ
CD	4	28	7.9198	0.0002**	0.1155	0.4621
TR	9	63	0.3187	0.9659	0.0056	0.0507
CD TR	36	252	0.8169	0.7634	0.0079	0.2848
SS	7				0.2369	1.6586
SS CD	28				0.0146	0.4084
SS TR	63				0.0177	1.1124
SS CD TR	252				0.0097	2.4409

** F (4,28) 0.001 = 6.25.

Table 12.4H Post-hoc Comparisons of the Mean Spatial Frequency Shift Magnitudes generated under the Five Viewing Conditions using the Scheffé Test (Hays, 1963).

1). Monocular Left and Monocular Right vs Binocular Viewing Magnitudes.

Criterion = 0.002967

Comparison = 0.000576

The difference between the magnitudes in the monocular and binocular conditions is not significant.

2). Monocular Left and Right vs Transfer Left to Right and Right to Left.

Criterion = 0.0019783

Comparison = 0.005625

The spatial frequency shift is significantly greater in the two monocular conditions than for the transfer conditions at the 5% level.

Normalised Transfer Measures

Measures of Ocular Asymmetry based on the Mean Magnitude of the Transferred Spatial Frequency Shift expressed as a Percentage of the Monocular Viewing Condition of the Tested Eye.

The mean transfer values of the spatial frequency shift can be expressed as a percentage of the monocular adapt and test condition of the eye that has been tested (these are shown in Table 12.2). These values, referred to as the normalised transfer data or measures can be used to derive a measure of ocular asymmetry using the following formula:

$$\text{Ocular Asymmetry Score} = \frac{\dfrac{LE - RE}{RE - RE} - \dfrac{RE - LE}{LE \quad LE}}{\dfrac{LE - RE}{RE \quad RE} \qquad \dfrac{RE - LE}{LE \quad LE}}$$

$\dfrac{LE - RE}{RE \quad RE}$ = Transfer data taken from Table 12.2.

$\dfrac{RE - LE}{LE \quad LE}$ = Transfer data taken from Table 12.2.

Table 12.5H below shows the ocular asymmetry scores for each subject using this normalised transfer data.

Table 12.5 Measures of Ocular Transfer

Subjects:	
SM	-0.115
DM	-0.123
PR	-0.266
PC	-0.018
EM	-0.159
EB	-0.056
SW	+0.290
SK	+0.145

The mean degree of asymmetry (ignoring the sign) is 0.15.

Ocular Asymmetry Measures Derived from the Normalised Interocular Transfer Data and Measures of Ocular Asymmetry Derived from the Previous Experiments.

The above measures were compared with the following:

1). The large disparity depth discrimination measures (1) and the correlation coefficient is r = 0.56, which is not significant (see Fig 12.4 page 216).

2). The binocular rivalry measures of ocular asymmetry and the correlation coefficient is r = 0.52, which is not significant.

Discussion

The magnitude of the transferred spatial frequency shift with the normalised data is expressed as a percentage of the monocular spatial frequency shift of the tested eye. This monocular viewing condition may have a larger or smaller monocular spatial frequency shift. In this study five subjects had greater transfer from the dominant eye to the non-dominant eye (using the large disparity definition) and had smaller aftereffects in the monocular condition of the tested eye (ie. the non-dominant eye). Therefore, it would be expected that the ocular asymmetry scores would be smaller when this transfer is expressed as a percentage of the monocular condition of the dominant eye ie the adapted eye. The monocular spatial frequency shifts analysed in terms of the large disparity depth discrimination measures did not differ significantly between the dominant and non-dominant eyes, small differences in these magnitudes would change the degree of asymmetry. Therefore a close agreement between these measures and those in Table 12.4 would not be expected.

(1)The correlation coefficient of the above interocular transfer measures and the small disparity depth measures is r = 0.22 which is not significant.

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